Office of the Chief Scientist for Human Factors

Human Factors General Aviation

Program Review
FY01

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The Federal Aviation Administration Office of the Chief Scientific and Technical Advisor for Human Factors (AAR-100) directs a general aviation research program that focuses on reducing fatalities, accidents, and incidents within the general aviation flight environment. This environment is defined as all flights that are conducted under FAR Part 91 as well as the general aviation maintenance community. The research addresses better methods for the detection, classification, and reporting of human factors accidents; developing certification and flight standards and guidelines based on human factors research, and identifying and implementing intervention strategies to impact general aviation accidents.

The following report summarizes projects between October 1st, 2000 and December 31st, 2001. These projects attempt to address requirements identified by the Federal Aviation Administration Flight Standards and Certification offices. The intent of this report is to allow Federal Aviation Administration sponsors to determine whether their requirements have been satisfactorily addressed, allow investigators to receive feedback from Federal Aviation Administration sponsors and other interested parties, and to provide feedback to the AAR-100 general aviation program manager on the quality of the research program. Basically, this document is a means of holding each group (sponsor, investigator, AAR-100 program manager) accountable to ensure that the program is successful.

In FY01, the general aviation research program distributed $634,000 contract dollars to eight performing organizations. In addition, some of these projects received supplemental support from the Civil Aerospace Medical Institute, Oklahoma City, OK. These projects are described in Appendix I and the requirements that are mapped to these projects are located in Appendix II.

Appendix III lists the FY02 funded projects ($606,000 contract dollars) and the proposed FY03 (estimated $625,000 contract dollars) and FY04 projects.

Address questions or comments to:

William K. Krebs, Ph.D.

Appendix I

Human Factors General Aviation

FY01 Project Summaries

Primary investigators submitted project summaries via world-wide-web. A newly created interactive web-based system modeled after the Office of Naval Research and the National Science Foundation was developed to standardize the yearly report submitted to the Office of the Chief Scientist for Human Factors. The reporting system can be found at http://www.hf.faa.gov/report

Project Title: *Causal Factors of Accidents and Incident Attributed to Human Error*

Primary Investigator: Dr. Scott Shappell, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: scott_shappell@mmacmail.jccbi.gov)

Co-Primary Investigator: Dr. Doug Wiegmann, University of Illinois, Savoy, IL (e-mail: dwiegman@uiuc.edu)

FAA Sponsor Organization: AFS-800 (POC: Michael Henry)
Sponsor's Requirement Statement: to identify potential data sources to identify causes of general aviation human error accidents as well describe potential remedies. The outcome of the research should develop and standardize methodologies for identifying, defining, and monitoring human error based incidents and accidents.

Research Project's Goal: The goal of this program is twofold. First, the analysis of all General Aviation and Commercial Aviation accidents between 1990 and present will allow the FAA to develop "data-driven" interventions based upon the accident record. In other words, research will be aimed at specific types of human error prevalent in the accident data, not human error in general or specific error forms based on opinion and conjecture. To date, this effort has led to changes within the GA safety program (AFS 800) and two Safer Skies efforts (Aeronautical Decision Making JSAT and the General Aviation Data Improvement Team). However, a finer-grained analysis of specific error forms such as skill-based errors, decision errors, perceptual errors, and violations as well as the preconditions for those unsafe acts is required. Future efforts will be directed at a better understanding of the specific types of errors inherent in the accident record.

The second goal of the program is to enhance the level of detail and quality of human factors accident investigation. It is well known that while the accident record is rich with data describing "what" occurred (e.g., the pilot failed to lower the landing gear), the identification of "why" the error occurred is inadequate. Using HFACS, or a similar human error system, another aim of this program is to provide the NTSB and FAA field investigator the tools necessary to perform a comprehensive human factors accident investigation. Efforts toward these ends has already begun using HFACS.

Best Accomplishment: The human factors analysis of all fatal and non-fatal general aviation accidents occurring between 1990 and 1998 has been completed. To date, over 14,000 GA accidents have been analyzed by five independent raters (all were certified flight instructors and GA pilots) using HFACS.

Project Summary: Scientists at CAMI and the University of Illinois have continued their investigation of the application of the Human Factors Analysis and Classification System (HFACS) taxonomy with civil aviation accidents. The human factors analysis of all fatal and a random sample of non-fatal general aviation accidents occurring between 1990 and 1998 has been completed. To date, over 14,000 human causal factors associated with nearly 5,000 GA accidents have been analyzed (2,770 fatal and 2,212 non-fatal accidents) by five independent raters (all were certified flight instructors and GA pilots) using HFACS. The analysis determined that roughly 80% of all general aviation accidents are attributed, at least in part, to skill-based errors and that many of those are associated with deficiencies in training and/or other issues of proficiency and currency. In addition, fatal accidents were four times more likely (roughly 40% of all accidents examined) to be associated with violations of the rules, than non-fatal accidents (only 10% of non-fatal accidents examined). An equal percentage of decision errors (roughly 40%) were associated with both fatal and non-fatal accidents examined, while perceptual errors were associated with nearly 10% of the accidents examined. The analysis of the remaining non-fatal GA accidents is ongoing with an early FY02 completion date. Results from the HFACS analysis have been incorporated into two Safer Skies initiatives (Aeronautical Decision Making JSAT and the General Aviation Data Improvement Team).

Scientific and Technical Objectives: The objectives of the HFACS project at CAMI are to conduct applied human factors analysis of general aviation and commercial accident reports to obtain objective, scientifically derived data that will aid in identifying data-driven intervention and mitigation strategies for reducing the number of accidents and incidents in the aviation community. A secondary objective is to provide a scientifically derived human factors approach for accident investigation in the field to improve both the quality and quantity of human factors data obtained in accident and incident investigations.

Technical Approach: Accident data was obtained from the NTSB and FAA for analysis using HFACS. All fixed-wing and rotary wing aircraft were included in the initial analyses (i.e., homebuilt, balloons, and gliders were not included). Causal factors associated with each accident were then classified into HFACS causal categories independently by five GA pilots. All raters were certified flight instructors (mean flight hours = 3,530). After training on HFACS (training consisted of a Four-hour workshop on HFACS; Practice coding 20 accidents as a group; and practice coding 50 accidents independently, followed by a review/consensus meeting) each pilot was assigned 1/3 of the accidents for a given year. Raters were instructed to independently code only those cause factors that were identified by the NTSB (no new cause factors created). Each pilot was then randomly paired with a second pilot who coded the same set of accidents to compare codes and achieve consensus. Pilots were then assigned another 1/3 of the accidents for a particular year and randomly paired with another pilot. This process continued until all the accidents had been coded.

Results: An examination of the fatal accident data has revealed several heretofore, unknown facts regarding fatal GA accidents. First, there has been little impact of efforts to date on specific types of human error associated with fatal GA accidents (i.e., no significant positive trends were identified within the four error categories (decision errors, skill-based errors, perceptual errors, and violations). This is in direct contrast to what has been reported previously in military and commercial aviation using HFACS. Second, skill-based errors have been associated with 4 out of every 5 accidents (80%) since 1990. These skill-based errors are primarily technique (stick-and-rudder) type errors indicating failures associated with training and currency/proficiency. Third, nearly 40% of all fatal GA accidents are associated with violations of the rules, and are typically the result of “continuing” flight into instrument meteorological conditions when authorized visual flight rules only. It is important to point out that these violations are “willful” departures from the rules and not simply inadvertent flight into the weather (classified as a decision error). Like violations, decision errors were also associated with nearly 40% of all fatal accidents, but perceptual errors (often due to visual illusions and spatial disorientation) were associated with less than 15% of all fatal accidents. It should be pointed out that many of our current intervention strategies and research efforts have been aimed at these last two error forms.

The pattern of results was similar for non-fatal GA accidents. Again, the trends across the years were relatively flat, except for a sharp decline in skill-based errors evident in 1998 (note: this was not due to a small sample size, since it represents over 250 accidents). As with fatal accidents, skill-based errors were associated with more accidents than any other error form, averaging roughly 80% of the accidents examined. Skill-based errors were followed by decision errors, which were associated with a little over 35% of the accidents and violations, and perceptual errors (less than 10%).

Impact/Applications: Data generated from the HFACS project has been briefed to a variety of committees and organizations within the FAA, NASA and the NTSB. In each case, the data generated has been incorporated into existing programs to augment or modify goals and plans of that organization. For example, as part of the Safer Skies initiative, Drs. Shappell and Wiegmann have been active participants in the Aeronautical Decision Making JSAT (ADM JSAT) and General Aviation Data Improvement Team (GADIT) in Washington, DC. In both instances, the results of the GA HFACS project have served as cornerstones for human factors data associated with GA accidents and has been integrated into reports out of the committee. In each case, a recommendation has been made to integrate HFACS into the investigative process in the field. As a result, Drs. Shappell and Dr. Wiegmann (Univ. of Illinois) presented there analyses of all General Aviation accidents occurring between 1990-98 to the NTSB (Drs. V.

Ellingstad, D. Bruce, and E. Byrne) and ASY-1 on separate days. The intention was to brief the NTSB on the progress thus far and begin discussions on hosting the HFACS data on either the NTSB or NASDAC web sites. Extensive briefings have also been conducted with AFS-800 and ACE-100 (FAA Sponsors of the project). Data from these briefings has been incorporated into several intitiatives at AFS-800 and a request has been made for additional analyses in FY02 and FY03.

Technology Transfer: none

Journal Articles:

Shappell, S. and Wiegmann, D. (2001). Beyond Reason: Defining the holes in the Swiss Cheese. Human Factors in Aviation Safety, 1(1), 59-86.

Wiegmann, D. and Shappell, S. (2001). Human error analysis of commercial aviation accidents: Application of the Human Factors Analysis and Classification System (HFACS). Aviation, Space and Environmental Medicine, 72, 1006-1016.

Wiegmann, D. and Shappell, S. (2001). Human error perspectives in aviation. International Journal of Aviation Psychology, 11, 341-357.

Wiegmann, D. and Shappell, S. (1999). Human error and crew resource management failures in Naval Aviation mishaps: A review of U.S. Naval Safety Center Data, 1990-96. Aviation, Space and Environmental Medicine, 70, 1147-1151.

Shappell, S. and Wiegmann, D. (1998). A human error approach to accident investigation: The Taxonomy of Unsafe Operations. International Journal of Aviation Psychology, 7, 269-291.

Wiegmann, D. and Shappell, S. (1997). Human factors analyses of post-accident data: Applying theoretical taxonomies of human error. International Journal of Aviation Psychology, 7, 67-81.

Books or Chapters: none

Technical Reports:

Wiegmann, D. and Shappell, S. (2001). A human error analysis of commercial aviation accidents using the Human Factors Analysis and Classification System (HFACS). Office of Aviation Medicine Technical Report No. DOT/FAA/AM-01/3. Civil Aeromedical Institute, Oklahoma City, OK 73125.

Shappell, S. and Wiegmann, D. (2000). The Human Factors Analysis and Classification System – HFACS. Office of Aviation Medicine Technical

Report No. DOT/FAA/AM-00/7. Civil Aeromedical Institute, Oklahoma City, OK 73125.

Conference presentations/abstracts: none

Patents Issued or Pending: none

Honors:

1. Dr. Shappell has been elected Fellow of the Aerospace Medical Association and Associate Editor of Aviation, Space and Environmental Medicine. He is also an Associate Editor of the International Journal of Aviation Psychology and peer reviewer for four other journals.

2. Dr. Wiegmann is an Associate Editor of the International Journal of Aviation Psycholgy and peer reviewer for four other journals.

Related Projects:

1. Julia Pounds (CAMI) - FAA JANUS Project to harmonize HFACS with EUROCONTROLs HERA framework for use in Air Traffic Control.

2. Jim Luxoj (Rutgers University) - NASA funded project that utilizes HFACS data and Bayesian Belief Networks to predict the efficacy of intervention strategies.

3. John Schmidt (U.S. Naval Safety Center) - FAA/NASA funded project for the development of maintenance extension of HFACS.

4. Doug Wiegmann (U of Illinois) - FAA funded project examining organizational influences on human error.

Project Title: *Continued VFR Flight into IMC: An Empirical Investigation of the Causes*

Primary Investigator: Dr. Doug Wiegmann, University of Illinois, Savoy, IL (e-mail: dwiegman@uiuc.edu)

FAA Sponsor Organization: AFS-820 (POC: Anne Graham)
Sponsor's Requirement Statement: Weather related accidents and incidents still remains one of the major causes of general aviation accidents. This research program continues to address countermeasures and advances in training, technologies, and regulations to significantly reduce this GA issue.

Research Project's Goal: The ultimate goal of this research program is to develop intervention strategies which can be used to promote safer and more effective decision making in VFR cross-country flight. Such tools can only be effective, however, if they are based on a sound understanding of the behavioral and psychological mechanisms which govern decision making in VFR cross-country flight.

Best Accomplishment: One manuscript describing a study related to this project has been accepted for publication in "Human Factors," which is one of the top journals in this area.

Project Summary: General aviation (GA) accident statistics indicate that visual flight rules (VFR) flight into instrument meteorological conditions (IMC), or unqualified flight into bad weather, is a major safety hazard within general aviation. Historically, very little research has been conducted to identify the factors that influence VFR pilots' decisions to risk flying into deteriorating weather conditions. Without an empirical understanding of these factors, decision-making training within pilot training programs has been based largely on common sense and intuition. Hence, such programs have been relatively ineffective in reducing the occurrence of such accidents. To address this issue, the present project involves both archival and laboratory research to empirically explore the factors that contribute to pilots' decision to "press on" into deteriorating weather. To date, one database study and three laboratory studies have been conducted. These studies have all pointed to pilots' situation assessment and previous flight experiences as key factors influencing pilots' decisions to continue VFR flight into IMC. Future research will explore methods for improving situation assessment to prevent accidents, as well as developing methods for reducing the consequences (i.e., improve recovery) of inadvertent encounters with adverse weather.

Scientific and Technical Objectives:
1. A comprehensive analysis of all VFR into IMC accidents that occurred between 1990 and 1997 was performed using database records maintained by

the FAA and NTSB. Fatality rates, pilot demographics and accident cause-factors were examined and compared to other GA aircraft accidents. In general VFR-IMC accidents were more likely to, (a) be fatal, (b) involved less experienced pilots, and (c)have other people on board the aircraft.

2. Pilots' decision to continue or divert from a visual flight rules flight (VFR) into instrument meteorological conditions (IMC) were investigated using a dynamic simulation of a hypothetical cross-country flight. Differences in situation assessment, risk perception and motivation between pilots who chose to continue or divert from VFR flight into IMC were examined. Accuracy of visibility estimates, appraisal of one's own skill and judgment and frequency of risk-taking behavior were most important in predicting whether a pilot would continue or divert the flight.
Products:

3. An experiment was also performed to examined whether the location at which adverse weather is encountered, relative to the destination airport, affects pilots' willingness to "press on" into deteriorating weather conditions. In this experiment, general aviation pilots complete a cross-country flight during which they made weather-related decisions either early or late during the flight. Specifically, participants encountered IFR conditions either 15-min into a 60 min cross country flight, or 45 minutes into the flight (i.e., 15 minutes from the destination airport). The effects of these manipulations on pilots' decisions to either continue or divert the flight, as well as their perceived risk and situation awareness, were assessed. Results indicated that pilots who encountered the weather early during the flight were more likely to continue the flight into the weather. These pilots also had poorer assessment of the actual weather conditions, indicating that situation assessment is a major factor in pilots' decision to continue VFR flight into IMC.

Technical Approach: In a typical experiment, participants are introduced to a Frasca 142 flight simulator that is configured as a Cessna 172. The simulator has a full set of instruments as well as a radio stack. All the necessary controls (yoke, rudder pedals, throttle) are also available. An Evans and Sutherland SPX 2400 visual system is used to project a 135° view of the outside visual world. This system is capable of displaying real time weather changes and three-dimensional fixes along the flight route.

After a practice flight (approximately 20 minutes), participants are provided with a checklist, map and flight plan which detailed the route and the fixes along the route they are to fly for the experiment. They are provided with Terminal Aerodrome Forecasts (TAF), an aviation routine weather report (METARS), and Winds Aloft information for the day of the flight. For example, participants may be told that the weather conditions at take-off are above VFR minimums (5 statute miles [sm] visibility, 5000ft MSL cloud ceiling). Winds are forecasted to be from the northwest (310) at 8 knots with a 20% chance of rain later that evening.

Participants are given as much time as they need to review the weather information and other flight planning details.

Participants are instructed to treat the simulated cross-country flight like any that they would make in the real world. They are told that they are responsible for monitoring aircraft systems for possible failures, as well as scanning for other possible traffic or changes in the weather. They are also informed that these problems might not necessarily occur. However, in the event that they do decide to divert from the planned flight, they are informed that they could choose any alternate airport that is on the map, including returning to the departure airport. They are instructed to inform the experimenter if and when they decided to deviate from the original flight plan and to press a pre-determined key on the simulator to mark the point in the flight at which this decision was made.

During a typical experiment, participants encounter degrading weather conditions somewhere along their flight path. For example, in a recent experiment, participants in a short-group encountered weather conditions that degraded to IMC, reaching 2 sm visibility and 1500 ft MSL cloud ceiling approximately 30 NM into the flight (approximately 15 minutes from the departure airport). For participants in a long-group, weather conditions decreased to 2 sm visibility and 1500 ft MSL cloud ceiling approximately 90 NM into the flight, which was roughly 30 NM or 15 minutes from the destination airport. For both groups, the deterioration of weather conditions (lowering of cloud ceiling and reduction in visibility) occurred when pilots were at straight and level flight. Weather degraded gradually and at the same rate for both groups, beginning roughly 15 NM from the point at which conditions would be at their worst. It should be noted that pilots could not transition to an IFR flight plan into the destination airport, because the airport did not have the facilities capable of supporting an instrument approach. Both groups had a relatively large airport available as a diversion point at approximately equal distances (roughly 15 minutes away) from the point at which the weather began to degrade. Participants in most experiments are allowed to continue the flight until they either decide to divert the flight to an alternate airport or until they "crash" the airplane.

Following the flight simulation, participants complete a post-experimental questionnaire to examine the participants' assessment of the weather conditions, in terms of visibility and cloud ceiling, at the time the program was terminated.

Results: The results of this research indicate that VFR flight into IMC is due to problems at various points in the decision making process. Both situation assessment (i.e., weather evaluation) and perceived risk of flight into adverse weather are important factors affecting pilots' choice to press on into deteriorating weather. Previous flight experience also appears to play a role, since experience affects both of these components of a pilot's decision-making process (i.e. situation assessment and risk perception). However, the role of experience is difficult to determine. For example, experience may make a pilot better at diagnosing weather conditions, and hence more experienced pilots may be more likely to divert from flight into adverse weather. However, experience can also make pilots more confident in their abilities, and therefore reduce their perceived risk and promote VFR flight into IMC. Furthermore, there are numerous categories of experience in aviation (total flight hours, cross-country hours, instrument time, etc.).We are therefore, exploring these issues in more detail in current studies.

Impact/Applications: The results of this research will help the FAA sponsor determine the types of intervetion stategies that are likely to be effective at promoting safer and better decision making during VFR cross-country flight. Such determinations by the FAA sponsor should be based on a sound understanding of the behavioral and psychological mechanisms which govern decision making in VFR cross-country flight.

Technology Transfer: none

Journal Articles:

Goh, J. & Wiegmann, D. A. (2001). Visual flight rules flight (VFR) into adverse weather: An empirical investigation of the possible causes. The International Journal of Aviation Psychology, 11 (4), 259-379.

Wiegmann, D., Goh, J., & O'Hare, D. (in press). The role of situation assessment and experience in pilots' decisions to continue visual flight rules (VFR) flight into adverse weather. Human Factors.

Goh, J. & Wiegmann, D.A. (accepted pending revision). Analyzing the causes of VFR flight into IMC accidents: Implications for aeronautical decision-making theories and training. Aviation, Space, and Environmental Medicine.

Books or Chapters: none

Technical Reports:

Wiegmann, D. & Goh, J., and O'Hare, D. (2001). Pilots' decision to continue visual flight rules (VFR) flight into adverse weather: Effects of distance traveled and flight experience (Technical Report ARL-01-11/FAA-01-3). Savoy, IL: University of Illinois, Aviation Research Lab.

Wiegmann, D. A., & Goh, J. (2000). Visual Flight Rules (VFR) flight into adverse weather: An empirical investigation of factors affecting pilot decision making. (Technical Report ARL-00-15/FAA-00-8). Savoy, IL: University of Illinois, Aviation Research Lab.

Conference presentations/abstracts:

Goh, J. & Wiegmann, D. A. (2001). An investigation of the factors that contribute to pilots' decisions to continue visual flight rules flight into adverse weather. Proceedings of 45th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA.

O'Hare, D., Owen, D. & Wiegmann, D. A. (2001). The "where" and the "why" of cross-country VFR crashes: Database and simulation analyses. Proceedings of 45th Annual Meeting of the Human Factors and Ergonomics Society, Santa Monica, CA.

Goh, J. & Wiegmann, D. A. (2001). Visual flight rules (VFR) flight into instrument meteorological conditions (IMC): An analysis of the accident data. Proceedings of the 11th Symposium on Aviation Psychology, Ohio State University.

Patents Issued or Pending: none

Honors: Juliana Goh, a graduate research assistant on this project, received the 2001 Amelia Earhart Award for her outstanding contribution to aviation safety.

Related Projects: This project is related to research being done at CAMI on weather displays and ADI failures.

Project Title: *Development of Web-Based Safety Training*

Primary Investigator: Dr. David Hunter, Federal Aviation Administration (AAM-240), Washington, D.C. (e-mail: david.hunter@faa.gov)

FAA Sponsor Organization: AFS-820 (POC: Anne Graham)
Sponsor's Requirement Statement: none

Research Project's Goal: to guide the development of future web-enabled training derived from existing video-based training programs

Best Accomplishment: The principal accomplishment has been the demonstration of the feasibility of creating synchronized still-pictures and audio narrative from existing full motion videos and the hosting of those programs on a live web site.

Project Summary: Analyses were conducted to determine the formats which might best be used for delivery of video-based training over the internet. These analyses included tests of uncompressed video and three size-reduction approaches: frame size and frame rate reduction, streaming video compression, and still images with audio (slide show). A 180 second video test extract from the CD-ROM training product, "Creating a Personal Minimums Checklist". In its original uncompressed format this video extract was 86,045 KB in size, requiring 478 KB per second of throughput to stream without interruption – far exceeding the identified minimum constraint of 6.5 KB per second. Of the two video formats tested, video streaming offered the best performance in terms of quality of presentation while remaining within the transmission rate. However, the use of video streaming requires the use of dedicated server hardware optimized for that function and, assuming multiple simultaneous remove users, access to more bandwidth than is currently available on the FAA experimental web site access line. Under these constraints, the best short-term solution was found to be still-images coupled with a synchronized audio.
On the basis of those analyses, a web-deliverable version of the "Personal Minimums Checklist" training program was developed using the slide-show format. That web-enabled version was then published to the experimental web site http://FlySafe.faa.gov, and visitors to that web site were invited to access the training and to provide feedback.

Scientific and Technical Objectives: The objective of this effort was to evaluate different approaches to the conversion of full motion videos to a web-enabled format. The results will prove applicable to future web-based training development planned, primarily, by the Flight Standards Service, as they attempt to broaden the range of safety-related training services available to general aviation pilots.

Technical Approach: Three methods for the reduction of file size were evaluated for their effect on transfer rate requirement and video quality. These methods were compared to the uncompressed full-motion video as a baseline. Transfer rate requirements for each of the formats were calculated for 28.8 and 56 KPBS connections, and the quality of the video were evaluated by inspection.

Results: This effort demonstrated the difficulties associated with using uncompressed video, reduced size video, and streaming video when converting existing full-motion video to a web-enabled format. It also demonstrated that still-pictures accompanied by a synchronized audio can approximate the full-motion video, while remaining well within the server and remote-connection limitations of delivery over the internet.

Impact/Applications: This study will help the sponsor (Flight Standards Service) in the development of future web-based training programs, by demonstrating the feasibility of converting existing full-motion video to a web-enabled version.

Technology Transfer: The results of this effort will be transferred to the conversion of additional safety-related training programs that contain full-motion video.

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts: none

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *Loss of Primary Flight Instruments During IMC*

Primary Investigator: Dr. Dennis Beringer, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: dennis_beringer@mmacmail.jccbi.gov)

FAA Sponsor Organization: AFS-800 (POC: Michael Henry)
Sponsor's Requirement Statement: This requirement objective is to identify the probably pilot response to loss of primary flight instruments during IMC and provide recommendations to significant reduce the potential of accidents and incidents. Research should identify training, technology or regulatory solutions.

Research Project's Goal: The results of the studies will be used as a baseline for comparison with future data that will, hopefully, be collected using moving-base simulators. These comparisons will help to define the limitations on generalization that can be done from both fixed-base and moving-base simulators as a function of type of flight task. The results are also being used to define minimum requirements for system-failure warnings and to further clarify and shape policy for the use of back-up attitude indicators, specifically those intended to replace existing instrumentation.

Best Accomplishment: Data were collected that had direct bearing on the question of allowing replacement of the turn coordinator with a back-up attitude indicator. The data also provided a rank ordering of relative merit of various instrument combinations that could be used by General Aviation pilot to allow safe continuation of a flight under vacuum-failure conditions in IMC.

Project Summary: Sixty pilots were exposed to a vacuum-system failure during a flight simulation, 48 in a Piper Malibu simulator and 12 in a simulated Cessna 172. Both simulations were conducted in the Human Factors Research Laboratory at the Civil Aerospace Medical Institute, Oklahoma City. Instrumentation failure was varied to produce five different remaining display

Scientific and Technical Objectives: A study was conducted to compare pilot eye movements and flight performance attainable using highway-in-the-sky (HITS) format displays in both head-up display (HUD) and head-down display (HDD) configurations and conformal (with outside world) and compressed forms within the HUD, with a baseline conventional-instruments condition. Results were mixed, and the HUD was not clearly superior to the equivalent HDD when comparing flight technical error. Workload appeared to be comparable for the HITS formats but slightly elevated for specific tasks in a baseline condition using conventional instrumentation. The need for a conformal HUD for general aviation operations was not supported for most flight operations, and pilots preferred the HUD over the HDD and the compressed HITS format over the conformal HITS or conventional instruments. Sponsors needed quantitative data regarding the actual dwell times to be expected when using a pathway-format display as concern had arisen in some applications that cognitive capture would occur (display thought to be "compelling").

Technical Approach: Experimental Design and Participants - Twenty-six GA pilots, all having more than 100 hours total flight time, participated in the study, with the conditions administered such that both within-subject and between-group analyses could be conducted. Three counter-balanced orders of the three display conditions (head-down compressed, head-up compressed, and head-up conformal) were presented. As a result of each display format appearing first in one of the orders, a between-groups examination could be performed on the first flights only, free of any intra-serial transfer effects. Thirteen pilots, who were still available at the time of the baseline-data request (some had moved out of state), were recalled six months after the initial sessions to fly the conventional instrumentation scenario.

Equipment/Displays. Data were collected using the Advanced General Aviation Research Simulator (AGARS), configured to represent a Piper Malibu, at the Civil Aerospace Medical Institute. Highway-in-the-sky primary flight displays (PFDs) were presented as monochrome (green) so that the head-down presentation would match that of the HUD. A Kaiser Optics LCD-projection HUD was used for the head-up presentations, while the head-down display was shown on a CRT, emulating a LCD approximately 11 inches across. The conformal version of the HUD showed approximately 22 degrees of the synthetic HITS presentation, while the compressed version squeezed about 40 degrees of the presentation into the same physical display width. The HITS used trough-type (rain gutter) symbology and a velocity-vector symbol to indicate flight-path trend. An Elmar head-mounted infrared eye-tracking device was used to monitor right-eye movements and fixations.

Procedure/Tasks: The session began with a short warm-up flight using conventional instruments. This was followed by a briefing concerning the HITS display and replay of a stored flight, allowing the participant to view HITS displays in operation. The pilot was further briefed concerning the locale for the flight (Albuquerque, NM) and the presence of significant terrain. This was followed by calibration of the eye tracker. Three 20-minute flight profiles followed, using each of the HITS formats once, with a short break between flights 2 and 3. The baseline procedure used a warm-up session with the conventional instrumentation and then one 20-minute flight.

Each HITS flight included a take-off and interception of the pathway, climb to cruise, enroute level flight, descent/approach, and landing, with four major heading changes required during the flight. The direction of required turns changed with each subsequent flight, although the distances flown were the same. Seven airborne targets were presented and pilots were instructed to report any traffic detected. Pilots were also required to perform a probe-reaction-time task. Data collected during the flight included digital flight technical error, eye-gaze point, and cockpit video/audio. A questionnaire was administered during the post-flight debriefing to determine pilots' responses to the HITS display. The baseline flight was similar in many respects but involved a vector to intercept a specified VOR radial inbound (similar to HITS downwind leg), followed by a procedure turn and approach using the ILS.

Results:
Successful Recovery: Clearly, the most important issue is whether or not the pilot is able to successfully complete the flight to a safe landing when encountering a vacuum-system failure in IMC. Of those pilots using the standard Malibu configuration (HSI), 25% would have impacted the terrain at a high rate of descent. Those using the back-up AI in addition to the HSI exhibited an 8% loss rate. Pilots having a DG that failed with the vacuum in place of the HSI had an 83% loss rate. In the configuration that would result if the petition for rulemaking were granted (back-up AI replaces TC; DG in place of HSI), the loss rate was 33%. A chi-squared analysis was conducted to statistically examine the two configurations of greatest interest, baseline ("Base" in Figure 4) and no turn coordinator (noTC), to determine the significance of removing the TC and replacing it with a back-up AI. The analysis revealed a significant difference between the two configurations ($p = .013$). Given that the difference in frequency distributions between the baseline and no TC was the least of all differences from the baseline, it is clear that all the other configurations also produced a significantly different response by the pilots from that found in the baseline. Thus, all other instrumentation configurations were a significant improvement over the baseline.

One precursor to loss of control that has been identified is an initial response to the failing AI of attempting to correct the apparent drift in bank using a rather authoritative aileron input. This was observed with the vast majority of pilots who lost control of the simulator, resulting in the aircraft banking in the opposite direction, often beyond an angle that is recoverable by using only the turn coordinator, compass, VSI, etc. Those individuals who carefully cross-checked instrumentation and did not initiate any control inputs immediately were almost uniformly successful in completing the flight (eye tracker and cockpit video-taped data). Time from failure to loss of control or flight termination was examined. Times were consistent across Malibu configurations (1 – 4), averaging close to 30 s. This is considerably shorter than the times reported by Martinez. However, the one loss in the Cessna 172 configuration required two minutes to develop (still significantly less than those reported by Martinez), with two rapid descents and recoveries before terminating within 200 ft of the ground at 132 mph airspeed and –6000 fpm vertical velocity.

These results underscore the differences that may be expected between high-performance aircraft and more docile training aircraft, and reinforce the observation that the Malibu simulator required focused attention to fly and was less “forgiving” than the Skyhawk simulation. It was clearly easier to get into trouble more quickly with the Malibu simulator.

Detection and Diagnosis: The majority of pilots indicated that they detected the “vacuum low” light first (18 of the 33 pilots having the light in their configuration) and then observed the precession of the AI. Additionally, observations during flights indicated that many pilots had difficulty ignoring the failed AI, and many actually removed an eye-tracker circular target from the panel and placed it in the AI hole to cover the instrument. Several indicated that they wouldn’t fly with a back-up AI unless they had instrument covers with them to obscure the failed instrument.

Pilot Experience Variables: Examination of the data indicated no systematic relationships between the likelihood of loss of control in the simulation and any of the flight-experience variables, nor was age a determining factor. A significant problem in interpreting the influence that experiential variables may have had on the outcome is that display configuration exerted a very strong influence and the sample sizes within a given display configuration were small, too small to allow detection of any but the most extreme effects within a group. Potential global (across-groups) contributions were either very weak or washed out by the display effect. Martinez had the advantage of having 24 individuals in a single display configuration and pilots who were all experienced in the specific aircraft being simulated, increasing the power through both a larger sample size and reduced variability. One can, however, look at a few of the variables in a descriptive manner. For example, the type of certification the pilot held did not result in a differential frequency of crashes: 32.0% (8 of 25) of the private pilots crashed, 29.2% (7 of 24) of the commercial pilots crashed. However, 62.5% (5 of 8) of the ATPs crashed (sample too small to be meaningful). Previous experience with a vacuum loss only improved pilot performance slightly. The data indicate that 29.4% (5 of 17) of the pilots reporting a previous vacuum-loss experience crashed, compared with 38.5% of the pilots with no previous experience. Pilot performance, again, only improved slightly if the pilot held an instructor certificate. Flight instructors lost control 30% of the time (3 of 10) whereas 36% (17 of 47) of the non-instructors experienced the same outcome.

Pilot Preference Data:

Back-up equipment. Of the 57 pilots for which data were available, 35 (61%) expressed a preference for a back-up AI, while 21 (37%) expressed a preference for a back-up vacuum pump, and one had no preference. The preference did not correlate significantly with age or any of the experience measures and was distributed by age group. One should keep in mind that the back-up vacuum pump will allow all the vacuum instruments to be driven (DG included), whereas these would be lost with a back-up electric AI.

Replacement of turn coordinator: The last 20 individuals in the study were queried concerning their opinion about replacement of the turn coordinator with a back-up AI. Table 5 shows the categorization of the responses of the 17 subjects for which both back-up equipment and TC replacement responses were available. Response was not correlated with age or, necessarily, experience. Although one might expect that those individuals preferring a back-up vacuum pump might also be the ones to oppose replacement of the turn coordinator, this was not entirely true. While 5 individuals did fit that description (31%), and 13% (3) fit the other expected category of those who preferred a back-up AI and thought TC replacement was acceptable, 56% (9) preferred a back-up AI but still wanted a turn coordinator on the panel. Overall in this sub-sample, the preference was 2.4:1 for the back-up AI, but was 4.6:1 in favor of keeping the TC.

Impact/Applications: The results of this effort rank-ordered pilot performance according to the type of instrumentation available during the vacuum failure, allowing the sponsor to directly determine the implications of using various combinations of instrumentation. This could then be applied directly to a rule-making question that had arisen regarding the appropriateness of using a back-up attitude indicator in place of other instrumentation required by the regulations.

Technology Transfer: none

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts:

Beringer, D. B. and Ball, J. D. (2001). When gauges fail and clouds are tall, we miss the horizon most of all: General Aviation pilot responses to the loss of attitude information in IMC. In Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society, 45, 21-25.

Beringer, D. B. and Ball, J. D. (2001). An example of general aviation simulation research for developing certification criteria and guidelines: Primary flight displays. In Proceedings of the 9th International Conference on Human-computer Interaction. Mahwah, NJ: Lawrence Earlbaum, Publishers, 849-853.

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *Pilot field-of-vision capabilities/limitations*

Primary Investigator: Dr. Dennis Beringer, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: dennis_beringer@mmacmail.jccbi.gov)

FAA Sponsor Organization: ACE (POC: Frank Bick)
Sponsor's Requirement Statement: The research objectives of this requirement is to develop human factors recommendations to assist in alleviating pilot error and increased pilot workload created by non-standard installations of avionics devices and other cockpit equipment in general aviation aircraft. The research will provide pilot field-of-vision limitations for design considerations.

Research Project's Goal: Sponsors needed quantitative data regarding the actual dwell times to be expected when using a pathway-format display as concern had arisen in some applications that cognitive capture would occur (display thought to be "compelling").

Best Accomplishment: none

Project Summary: An experiment was conducted comparing visual and flight performance between two locations of highway-in-the-sky format primary flight displays (one head-up, one head-down) and a conventional instrument panel (baseline). Data were analyzed and reported at three professional meetings which resulted in publications. Data were also provided to the sponsor.

Scientific and Technical Objectives: A study was conducted to compare pilot eye movements and flight performance attainable using highway-in-the-sky (HITS) format displays in both head-up display (HUD) and head-down display (HDD) configurations and conformal (with outside world) and compressed forms within the HUD, with a baseline conventional-instruments condition. Results were mixed, and the HUD was not clearly superior to the equivalent HDD when comparing flight technical error. Workload appeared to be comparable for the HITS formats but slightly elevated for specific tasks in a baseline condition using conventional instrumentation. The need for a conformal HUD for general aviation operations was not supported for most flight operations, and pilots preferred the HUD over the HDD and the compressed HITS format over the conformal HITS or conventional instruments.

Technical Approach:

Experimental Design and Participants: Twenty-six GA pilots, all having more than 100 hours total flight time, participated in the study, with the conditions administered such that both within-subject and between-group analyses could be conducted. Three counter-balanced orders of the three display conditions (head-down compressed, head-up compressed, and head-up conformal) were presented. As a result of each display format appearing first in one of the orders, a between-groups examination could be performed on the first flights only, free of any intra-serial transfer effects. Thirteen pilots, who were still available at the time of the baseline-data request (some had moved out of state), were recalled six months after the initial sessions to fly the conventional instrumentation scenario.

Equipment/Displays: Data were collected using the Advanced General Aviation Research Simulator (AGARS), configured to represent a Piper Malibu, at the Civil Aerospace Medical Institute. Highway-in-the-sky primary flight displays (PFDs) were presented as monochrome (green) so that the head-down presentation would match that of the HUD. A Kaiser Optics LCD-projection HUD was used for the head-up presentations, while the head-down display was shown on a CRT, emulating a LCD approximately 11 inches across. The conformal version of the HUD showed approximately 22 degrees of the synthetic HITS presentation, while the compressed version squeezed about 40 degrees of the presentation into the same physical display width. The HITS used trough-type (rain gutter) symbology and a velocity-vector symbol to indicate flight-path trend. An Elmar head-mounted infrared eye-tracking device was used to monitor right-eye movements and fixations.

Procedure/Tasks: The session began with a short warm-up flight using conventional instruments. This was followed by a briefing concerning the HITS display and replay of a stored flight, allowing the participant to view HITS displays in operation. The pilot was further briefed concerning the locale for the flight (Albuquerque, NM) and the presence of significant terrain. This was followed by calibration of the eye tracker. Three 20-minute flight profiles followed, using each of the HITS formats once, with a short break between flights 2 and 3. The baseline procedure used a warm-up session with the conventional instrumentation and then one 20-minute flight.

Each HITS flight included a take-off and interception of the pathway, climb to cruise, enroute level flight, descent/approach, and landing, with four major heading changes required during the flight. The direction of required turns changed with each subsequent flight, although the distances flown were the same. Seven airborne targets were presented and pilots were instructed to report any traffic detected. Pilots were also required to perform a probe-reaction-time task. Data collected during the flight included digital flight technical error, eye-gaze point, and cockpit video/audio. A questionnaire was administered during the post-flight debriefing to determine pilots' responses to the HITS display. The baseline flight was similar in many respects but involved a vector to intercept a specified VOR radial inbound (similar to HITS downwind leg), followed by a procedure turn and approach using the ILS.

<u>Results</u>:

Flight-performance variables: Examination of course-tracking errors by flights and display configurations indicated that mean errors were very similar in most cases, with the exception of mean horizontal root-mean-square error (RMSE), which was consistently greater for the conformal format. This reflected greater tracking error in the turns due to the loss of view of the path at some point in the turn and cutting inside turns to keep the path in view. This is consistent with the findings of Reising and Snow (2000), who found greater course, altitude, and airspeed errors during curved segments than on straight segments. Error was greatest when the conformal HUD was flown first or last, the former likely due to novelty, the latter most likely a result of having flown two compressed formats first. Comparison of data from the first flight only using a between-groups ANOVA indicated that both horizontal and vertical RMSE differences were significant ($p=.05$). In both cases, the error values for the two compressed formats were indistinguishable, but both were significantly smaller than for the conformal format.

Inasmuch as baseline flights used a different basis for guiding the flight path (altimeter, VOR needle; horizontal error measure and guidance indications were angular), displacement errors along the entire route were not considered comparable enough for direct comparison. Blunder errors (overshooting an intercept) were, however, observed to be more frequent using conventional instrumentation, even when intercept headings were given for joining the VOR courseline.

Target Detection Performance: Target 1, the C-130, was detected by nearly every pilot and at better than 4 miles distance, and was thus used as a check that participants were performing the search task. The remaining targets, all small GA aircraft, were used for the statistical analyses. Hit rate and detection distance data were collapsed across the 3 flights for the HDD and HUD conditions and repeated-measures ANOVAs indicated a significant effect of display for both variables (hit rate: $F(2,50)=7.25$, $p<.005$; detection distance, $F(2,50)=6.498$, $p<.005$). As depicted in Figure 5, hit rates for the 2 HUD conditions did not differ significantly, but both were reliably different from the head-down condition in post-hoc tests. Similarly, the trend was in the same direction for detection distance, although only the difference between the head-down and the head-up compressed displays attained significance. It is worth noting that targets were frequently not detected in the HUD condition until they actually entered the HUD visual space. Comparisons with the baseline rates/distances were conducted using data for only the 13 returning participants. Although the trend was similar for detection distance, the difference did not attain significance ($p<0.1$), largely due to variability of scores in the smaller sample. Hit rate differences were significant, however, and the hit rate for the baseline condition was significantly lower ($p<.05$) than for the compressed HUD but not different from the head-down HITS. Williams (2000) found an overall hit rate for airborne targets using a head-down HITS display format of 0.54, which is not inconsistent with the HDD findings here. However, the findings are at variance with Fadden and Wickens (1997), in that they found a consistently larger advantage for the HUD format; their targets, however, were all the same and the HUD image was not presented on an actual HUD device.

Eye-Tracking Results: Only those subjects who flew the baseline condition were included in the dwell and transition calculations. A within-subjects ANOVA for the four defined areas of interest revealed significant main effects of display condition for the percentage of dwell time on primary flight instruments ($F(3,36) = 21.581$, $p<.001$), looking out the window ($F(3,36) = 19.894$, $p<.001$), and time spent looking at other instrumentation and radios ($F(3,36) = 5.646$, $p = .003$). The percentage of dwell time spent looking at other areas was not statistically significant. Pair-wise comparisons revealed significant differences between the HUD conditions (conformal and compressed) and the HDD conditions (HDD and conventional instrumentation). Pilots spent significantly more time on the primary flight instrumentation and significantly less time looking out the windows or at other instrumentation while using either HUD format. There were no significant differences between the HUD conformal and compressed conditions for any of the dependent measures related to visual scanning. Also, there were no significant differences between the HDD condition and the conventional instrumentation for any of the areas of interest. Comparison of the HITS conditions for the full sample showed the same effects.

Probe Reaction Time Results: Probe reaction time (PRT) was assessed at 7 points along the course, both in turns and during the straight course segments. The pilot was to cancel a steady red LED mounted just beneath the glareshield by pressing a lighted key on a yoke-mounted keypad. The pilot was then required to fixate briefly on a flashing LED, in the same location, until that LED was extinguished so that centering of the eye tracker could be assessed. The PRT data contained a number of outliers (RTs greater than 10 seconds), concentrated in the first flights and the conformal HUD condition. These were removed to reduce the skewness, and all subsequent condition means fell between 1.5 and 2.5 seconds. Comparison of conditions indicated no significant differences between display conditions for either analysis with or without the outliers. The only tangible difference was the frequency of extreme scores in the first flight.

Rating Results:

HUD versus HDD. Some participants with more time in complex aircraft preferred the HDD location, indicating that it was less disruptive to their scans. Lower-time pilots, however, expressed a preference for the HUD, indicating that they believed it allowed for better surveillance of the surrounding airspace. Overall, the preference was: HUD(17), HDD(5), No preference (1), no data (3). Data for the baseline indicated that most rated the HITS display as being easier to fly than conventional instrumentation (mean of 3.14 versus 2.21 on a scale of 1=difficult to 7=easy, p=.0574).

However, 4 individuals, all over 30 years of age (34, 47, 50, 52), rated conventional instruments as easier to fly; of those decidedly favoring the HITS, 80% were under 30. Quantitatively, age was negatively correlated with higher ratings for the HITS (-.617) and total instrument hours was also negatively correlated (-.48).

Conformal versus compressed. - Overall, the compressed was preferred over the conformal. When examined more closely, the majority of this effect is due to a strong preference for the compressed format during turns. Although the conformal was rated as more acceptable for straight-and-level flight than for turns, it was still rated slightly lower than was the compressed.

Impact/Applications: Concern had been expressed in the certification community that highway-in-the-sky formats of PFD might be too compelling and would trap the pilot's scan and attention, reducing both the effectiveness of instrument-panel scanning and of out-the-window scanning. If this had been true and could have been translated into a reduction in safety as opposed to an equivalent level of safety for some applications, then some potentially beneficial PFD formats could have been denied certification. The data were helpful in demonstrating that the head-down highway-in-the-sky PFD was no more compelling than conventional instrumentation, and did not have a deleterious effect on the detection of other aircraft/traffic.

Technology Transfer: none

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts:

Beringer, D. B. and Ball, J. D. (2001). General aviation pilot visual performance using conformal and non-conformal head-up and head-down highway-in-the-sky displays. In Proceedings of the International Symposium on Aviation Psychology, Columbus, Ohio (in press).

Beringer, D. B. and Ball, J. D. (2001). A comparison of pilot navigation performance using conventional instrumentation, head-down, and head-up highway-in-the-sky primary flight displays. In Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society, 16-20.

Beringer, D. B. and Ball, J. D. (2001). An example of General Aviation simulation research for developing certification criteria and guidelines: Primary Flight

Displays. In Proceedings of the 9th International Conference on Human-computer Interaction, Mahwah, NJ: Lawrence Earlbaum, Publishers, 849-853.

Patents Issued or Pending: none

Honors: none

Related Projects: none

Project Title: *GA Training*

Primary Investigator: Dr. Kevin Williams, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: Kevin_Williams@mmacmail.jccbi.gov)

FAA Sponsor Organization: AFS-840 (POC: Tom Glista)
Sponsor's Requirement Statement: to identify potential near-term training improvements that could immediately have a positive effect on the reduction of general aviation accidents. In addition, this research should address training implications of future GA systems such as SATS.

Research Project's Goal: Results from the study will form a foundation of information that will be utilized in the future for various standardization and training requirements issues. Other planned studies will be looking at similar avionics packages, especially those being used in the Capstone program. As this new generation of avionics becomes more widely used and available, the FAA will have more and more of a need for knowledge regarding their potential impact on pilot situation awareness, training requirements, and safety. The future of general aviation avionics lies in the integrated multi-function/perspective primary flight display. Older instrumentation, which has sustained pilots almost since the beginning of flight, is finally nearing its end. This study, and similar studies looking at this technology, is required for the FAA to remain well-informed regarding the current and future state of the cockpit environment.

Best Accomplishment: Due to technical difficulties encountered at both performing entities (Embry-Riddle Aeronautical University and The Ohio State University), data collection has not yet begun on this research. However, as part of the overall program of research, a data reduction effort was undertaken of data gathered at the Oshkosh airshow in August, 2000 using a survey instrument developed at CAMI. The survey was intended to gauge various aspects of usability of a HITS/MFD display. A properly equipped simulator was used to demonstrate the displays to visitors at the airshow. Visitors were allowed to fly the simulator, and then they were asked to fill out the survey before they left.

Project Summary: New cockpit displays will, in the very near future, begin to replace traditional displays that have been the mainstay of general aviation (GA) aircraft for decades. One new type of display that has been given a great deal of attention is the Highway-In-the-Sky (HITS) display. A HITS (also called "pathway") display provides course guidance to the pilot using a perspective view of a path through the air. Interest in this type of display is not new, originating in the 1950s with the Joint Army-Navy Instrumentation Program. Until recently, however, the implementation of a HITS display was too expensive for most aircraft owners. Two technological breakthroughs have made it feasible for HITS systems to become a reality in most aircraft cockpits. One of these is an affordable Global Positioning System (GPS) receiver that provides real-time, accurate aircraft position information. The second breakthrough is the production of inexpensive, yet powerful, graphic display systems that are capable of providing real-time HITS depictions in the cockpit. Both of these technologies make HITS displays feasible for GA aircraft. Given the availability of more affordable HITS displays, the Advanced General Aviation Transport Experiments (AGATE) consortium, which is dedicated to the specification of a next-generation GA aircraft, has mandated the incorporation of the display as its top priority in judging the success of its program. In addition to the HITS display, a second type of display that will become more common in the GA cockpit is the multifunctional display (MFD). The MFD will be used to provide a variety of different types of information to the pilot to assist in navigation tasks. In addition to the display of terrain, traffic, and weather information, the MFD will be used to enter and edit flight plan information. This information will then be used to configure the HITS display. Currently, flight plan information is input into a GPS unit. It is expected that the functionality present in current GPS units will be transferred to the MFD. Future GA flights will be conducted using an MFD, integrated with a HITS display to plan and execute the flight. Such flights could be conducted in both visual and instrument meteorological conditions. The ease of learning and flying these displays will save potential pilots both time and money while earning a pilot certificate. They will also improve safety by improving the pilot’s awareness of the aircraft relative to the intended path of flight, terrain, traffic, and dangerous weather. The integration of advanced navigation displays with on-board flight planning displays has enormous potential to increase the safety and efficiency of flight operations within the NAS, especially general aviation operations. While there is potential for these displays to enhance safety by increasing situation awareness, there is also the possibility that a new level of complexity will be introduced in the cockpit that will have a negative impact on safety. Lessons learned from the introduction of GPS systems to the GA cockpit suggests that there are possible trade-offs between the increased navigational capability provided by new technology and the increased complexity that must be handled by the pilot/user of the system. In addition, the lack of a standard user-interface and other interface design shortcomings for GPS units has caused problems for pilots operating those units. With the advent of MFD’s much, if not all, of the functionality of the GPS systems will be migrated to these new displays. Research is required to study the training and certification requirements that these new systems will impose on the GA pilot. Such research will allow the development of minimum training standards for these systems and will provide useful information for officials involved in certifying these systems. This research should also support the development of user-interface guidelines for these new systems that will hopefully allow developers to avoid the problems encountered with the introduction of GPS systems. The purpose of the study is to compare the training requirements and ease of use of an integrated HITS/MFD display for performing instrument approach procedures to the requirements and ease of performing those same procedures using a currently certified GPS display. The results of the research will provide useful information for certification and standardization issues for these future displays.

Scientific and Technical Objectives: The main objective of the research will be to compare the use of a HITS/MFD display for making an instrument approach to the use of a GPS for making an instrument approach. Also to be tested is the relative complexity involved in having to change from one approach to a secondary approach during the flight. We expect that use of the more advanced displays will improve performance of the flight and reduce the complexity involved in selecting and changing the instrument approach. The information should be directly relevant to standardization and training issues.

Technical Approach: The experiment will be conducted using a research/training aircraft simulation device containing an integrated HITS display and MFD. Each of the selected research sites will perform the same standardized research protocol. Participants will receive training on the use and functionality of the displays and will be given one or more practice flights to ensure their familiarity with the displays. Participants should have at least a private pilot certificate. Familiarity with instrument approach procedures is also required.

For the experimental task, participants will plan, enter (using the MFD), and execute an instrument approach to an airport. During the flight, participants will be given tasks that will require them to interact with the MFD to gather information about weather, terrain, and traffic in the area. Shortly before beginning the initial approach, participants will receive a message from air traffic control requesting them to use a different runway from the one planned for the approach. This will require the pilot to change the flight plan so that the new approach can be executed. Participants will then fly the new approach until reaching the missed approach point, at which time the scenario will be halted and the experiment concluded.

During the flight, data will be collected regarding the ability of the pilot to interact with the MFD. Interaction errors (pushing the wrong button, backtracking through the menu structure, etc.) will be recorded. Automated data recording procedures will be used to the maximum extent possible. Video and manual recording of pilot actions will be used, if necessary, to supplement the automated data recording procedures. In addition, navigation errors relative to the pathway will be recorded to ensure that the pilot is maintaining appropriate control of the aircraft during interaction with the MFD.

As a control condition, a second group of participants will perform the same flight using conventional instruments and an onboard GPS receiver. Difficulties with planning, executing, and re-planning an instrument approach will be recorded and compared to the experimental condition. Time and resources permitting, the conditions might be treated as a within-subjects factor, with each of the conditions counterbalanced across subjects (AB, BA).

Results: The ERAU/OSU study is incomplete at this time. For the Oshkosh survey, the HITS display was generally well-received by both pilots and non-pilots participating in the Oshkosh demonstration. Older participants were slightly less favorable toward the displays. One reason for this is suggested by the stated level of computer expertise for the older pilots. The displays, especially as they were implemented in the simulator, are very similar to flight simulation programs currently on the market. In addition, the perspective view presented by the HITS display is similar to the type of perspective views shown in first-person computer game simulations. Older participants generally reported less expertise with these types of programs. It is likely that this lower level of familiarity was reflected in the evaluation of the displays. The HITS displays were viewed more favorably than conventional aircraft displays. One potential problem that HITS displays have is that they attract the attention of the pilot to the extent that the pilot often neglects to look outside of the cockpit. It is possible that both practice and training can resolve this problem. In summary, some of the results and comments from participants suggest that there are human factors issues that remain to be worked out; however, the interface shows much promise to this point.

Impact/Applications: Research is required to study the training and certification requirements that these new systems will impose on the GA pilot. Such research will allow the development of minimum training standards for these systems and will provide useful information for officials involved in certifying these systems. This research should also support the development of user-interface guidelines for these new systems that will hopefully allow developers to avoid the problems encountered with the introduction of GPS systems. The purpose of the study is to compare the training requirements and ease of use of an integrated HITS/MFD display for performing instrument approach procedures to the requirements and ease of performing those same procedures using a currently certified GPS display. The results of the research will provide useful information for certification and standardization issues for these future displays.

Technology Transfer: Results of this research will feed directly into future research planned for the Safe Flight 21 program, especially as it is related to the Alaska Capstone project.

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts:

Williams, K.W. (2001). AGATE avionics usability survey. Paper presentation at the 20th Annual Digital Avionics Systems Conference in Daytona Beach, Florida.

Patents Issued or Pending: none

Honors: none

Related Projects:

1. Safe Flight 21 project: Research on Alaska Capstone Phase I avionics full simulation study.

2. Safe Flight 21 project: Research on Alaska Capstone Phase I avionics training study.

3. Safe Flight 21 project: Research on Alaska Capstone Phase II avionics full simulation study.

Project Title: *CFIT/Terrain Displays*

Primary Investigator: Dr. Kevin Williams, Civil Aerospace Medical Institute, Oklahoma City, OK. (e-mail: Kevin_Williams@mmacmail.jccbi.gov)

FAA Sponsor Organization: ACE (POC: Jeff Holland)
Sponsor's Requirement Statement: The purpose of this research is to address CIT issues which were identified by the JSIT team. Research will focus on various countermeasures to include training, technology, and science-based regulations to significant reduce the occurrence of general aviation CFIT accidents.

Research Project's Goal: Results of this research should assist in future research on terrain awareness displays, including those used in the Alaska Capstone program.

Best Accomplishment: A research contract was provided to the Human Systems Information Analysis Center (HSIAC) to conduct an extensive literature review of display research related to cockpit terrain displays.

Project Summary: Manufacturers have been developing and marketing horizontal and vertical situation awareness displays for some time. The quality of the displays varies significantly. However, with the more recent advent of less expensive and higher quality color displays, there has been a significant increase in the quantity and sophistication of these systems. Unfortunately, the designs seem to be driven more by intuition, supposition, and marketability than by data. The effectiveness of some of these systems to prevent CFIT accidents is questionable. Research needs to be conducted to determine the minimal amount and type of information that should be presented to develop adequate situation awareness to avert CFIT-related accidents. Some key issues that need to be addressed include: Horizontal Situation Displays vs. Vertical Situation Displays vs. Both; Benefits/Detriments for 2-D & 3-D Displays; Minimum Display Size; Minimum Level of Detail and Quality of Terrain Depiction; Type and Form of Displayed Position-Terrain Information; Color Application Philosophy (e.g., darker colors for lower elevations); Desired Visual/Audio Alerts; Most Appropriate and Effective Cues to Alerting Pilot of an Impending Situation; Methods of Operation; Appropriate Use of Such Systems.
Significant Accomplishments: A research contract was provided to the Human Systems Information Analysis Center (HSIAC) to conduct an extensive literature review of display research related to cockpit terrain displays.

Scientific and Technical Objectives: The Human Systems Information Analysis Center (HSIAC) was asked to generate a Review and Analysis (R&A) for the Human Resources Research Division of the FAA CAMI that includes an annotated bibliography documenting the current cockpit terrain display systems research literature. Results indicate that an extensive body of literature has been generated to describe terrain display, moving map, and navigational aid characteristics. This report briefly summarizes the graphical terrain display design literature. Display concepts and criteria are discussed in reference to their application to navigational tasks and human perception and performance. Supporting bibliographic material is provided for a more in-depth investigation by FAA CAMI researchers.

Technical Approach: A keyword list and search strategy was developed and a search of both government and commercial literature databases was conducted to identify relevant information. The search strategy was employed by professional database researchers using the following in-house, government and commercial databases:

Results: Controlled Flight Into Terrain (CFIT) is one of the most problematic of all types of aviation accidents. Despite the varied circumstances surrounding CFIT accidents, they are most often attributed to poor situation awareness (Scott, 1996). A lack of situation awareness can arise in several different ways. The crew may be aware of the terrain in an area, but be unaware of their position and/or altitude. On the other hand, they may be aware of their altitude and position yet be unaware of the terrain. A third possibility exists where the crew is unaware of both the aircraft's position and the terrain in the vicinity. This range of possible situations is important because any attempts to reduce CFIT accidents by implementing cockpit terrain display technology must address all possible situations (Peterson, 1999).

The research indicates attention has been given to the design and implementation of different display formats to give pilots a better method of acquiring awareness of surroundings and situations important to their flight. Kuchar and Hansman (1993a) coined the term terrain situational awareness (TSA); i.e., the presentation of terrain information in a manner which allows the pilot to create a mental view of the terrain surrounding the aircraft, and proposed that improving TSA via new displays was the key to preventing CFIT. A broad review of the literature was undertaken, therefore, to capture the relevant terrain display design concepts and approaches that may facilitate TSA. The following sections briefly document that review. Supporting bibliographic material is provided for a more in-depth investigation by FAA CAMI researchers.

Impact/Applications: The Human Systems Information Analysis Center (HSIAC) performed a literature search on cockpit terrain displays. The search included plan-view, profile-view, and perspective-view terrain displays used in both single and multi-pilot cockpits. Topic areas of interest are the design and use of terrain displays as influenced by the following: Human perception and cognition; Human Factors, ergonomics, and cognitive design principles; Information management, information access, and display control; Attention and effort; User configuration, customization, automation, & standardization issues. An extensive body of literature on the topic of terrain display, electronic map, and navigation display design and implementation was identified; a portion of which is summarized in the body of this document. A complete bibliographic listing of relevant sources is provided as a resource to guide and support future FAA CAMI research efforts.

Technology Transfer: none

Journal Articles: none

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts: none

Patents Issued or Pending: none

Honors: none

Related Projects: Research on the Capstone project is directly related to this activity, and should serve to directly support the development of future research on terrain displays and the prevention of CFIT accidents.

Project Title: *Continued VFR flight into IMC: Situational Awareness or Risky Decision Making?*

Primary Investigator: Dr. David O'Hare, University of Otago, Dunedin, New Zealand. (e-mail: ohare@psy.otago.ac.nz)

Co-Primary Investigator: Dr. Doug Wiegmann, University of Illinois, Savoy, IL (e-mail: dwiegman@uiuc.edu)

FAA Sponsor Organization: AFS-820 (POC: Anne Graham)
Sponsor's Requirement Statement: Weather related accidents and incidents still remains one of the major causes of general aviation accidents. This research program continues to address countermeasures and advances in training, technologies, and regulations to significantly reduce this GA issue.

Research Project's Goal: The eventual outcomes of this research program include: enhanced understanding of the nature and characteristics of decision making in cross-country VFR flight; tools for enhancing decision making techniques (e.g. checklists, cockpit reminders, etc.); techniques for enhancing the training of cross-country VFR decision making (e.g. manuals, video tape, CD-ROM interactive programs, etc.); articles for pilot magazines, conference presentations, and articles for scholarly publication in peer-reviewed journals.

Best Accomplishment: We have been highly successful in customizing off-the-shelf software for use in a high fidelity cross-country VFR simulation on a high-end PC. Pilots exhibited a high degree of involvement with the simulation, including extensive planning, utilization of landmark cues for real-time navigation with standard sectional aeronautical charts, deliberation about flight continuation options, and some evidence of affective response (discomfort, anxiety) to the ominous weather and terrain cues that were manipulated.

Project Summary: Pilots planned and executed two simulated cross-country VFR flights (each of approximately 60 minutes duration), with dynamic weather and terrain conditions engineered to put the pilots into two different VFR-marginal positions by predetermined points along the route. In one flight, pilots flew low over coastal terrain under a rapidly lowering cloud base. In another, pilots found themselves on top of a broken cloud layer that was becoming solid overcast, over mountainous terrain. Pilots in one condition were able to use a simulated GPS in the planning and execution of their flights. Other pilots used traditional dead-reckoning navigation. Results showed a positive effect of pilot's recent experience on the decision to continue, and relatively small effects of situational awareness (position of aircraft) or assessment (identification of deteriorating weather). The pilots who discontinued each flight at the first predetermined decision point (a point on each flight where the weather had clearly changed, but remained close to, if not within, VFR-minima) were strongly differentiated from those who continued by decreased levels of comfort, globally heightened perceptions of risk, and increased thought applied to their decision. Collectively, these markers suggest heightened anxiety on the part of those pilots who discontinued the flight. The role of anxiety, or negative affective cues, on an aviation decision-making model is explored. Further research is needed to identify important sources of anxiety in this decision domain, and the factors (personal, environmental) that may have predisposed pilots to be particularly sensitive or insensitive to anxiety and its effect on aviation decision-making.

For many years, crashes involving visual flight rules (VFR) flight into instrument meteorological conditions (IMC) have been one of the most serious problems in general aviation. A recent report by the U.S. National Transportation Safety Board (NTSB, 1989) shows that although 'VFR into IMC' crashes are a relatively small proportion of the total number of GA crashes (4%), they account for 19% of the GA fatalities. In fact, 72% of 'VFR into IMC' crashes are fatal, compared to an overall figure of 17%.

Whilst the overall GA crash rate has been trending downwards in the United States over the past decade (NTSB, 1989), this has not been the case in other countries such as the U.K. or New Zealand. Even in the U.S., the decline in 'VFR into IMC' crash rates has been much less than the decline in overall GA rates. There is little doubt that human judgment and decision-making are critical elements of these crashes.

Jensen & Benel (1977) analyzed the NTSB records of GA crashes in the period 1970-1974, and found that whereas the majority of non-fatal crashes were associated with perceptual-motor activities (e.g. judgment of speed, distance, altitude etc), the majority of fatal crashes were associated with decisional processes (e.g. self assessment of skill, setting priorities, planning etc). In a recent analysis of nearly ten years fixed-wing air crash data from New Zealand (O'Hare, Batt, Wiggins, & Morrison, 1994), the same pattern was evident, with decisional activities accounting for over 60% of the fatal crashes.

Aviation writers have advanced many explanations for why VFR pilots would risk "pressing on" into deteriorating weather conditions. The most unhelpful 'explanation' has been to replace one unknown ("pressing on") with another, such as "get-home-itis". Other factors mentioned include over-confidence, carelessness, and lack of awareness (e.g. Bramson, 1988). Some support for the role of over-confidence comes from the NTSB review cited above. NTSB investigators cited over-confidence as a factor in approximately 19% of the 364 'VFR into IMC' crashes during the 1983-86 period. Indirect evidence for the other factors may be reflected in failures to obtain weather briefings, failing to file a flight plan, inadequate pre-flight planning and so forth. Following a particularly poor year for GA safety (1987), the U.K. Civil Aviation Authority set up a Study Group to review the accident record. Their report (CAA, 1988) contains much speculation on the factors contributing to the increase in errors related to weather conditions. The authors conclude that psychological factors such as 'excessive optimism', 'reluctance to admit limited capability' and 'lack of appreciation of real dangers' were behind the errors of judgment and decision making which led to the crashes.

In summary, the GA crash record in different countries shows that 'VFR into IMC' flight continues to represent a major hazard. Speculation as to the causes of this problem has focused on a wide variety of psychological factors such as over-confidence, lack of awareness, and risk-perception. The precise role of such factors remains highly speculative in the absence of well-designed empirical research. We propose to address this problem through a broad program of research directed at examining naturalistic sources of data (e.g. accident databases) and by developing an extensive laboratory program of controlled investigations into the nature and causes of pilot decision making when dealing with potential 'VFR into IMC' events. The ultimate aim of the proposed research is to develop intervention strategies that can be used to promote safer and more effective decision-making in VFR cross-country flight. Such tools can only be effective, however, if they are based on a sound understanding of the behavioral and psychological mechanisms that govern decision making in VFR cross-country flight.

Situational Awareness: In recent years there has been a flurry of research on situational awareness in pilots and air traffic controllers. In aviation, as in other complex dynamic systems, the operator's awareness of the current state of the system, and their expectations about the future state of the system are likely to have a significant impact on their overall level of performance. The 'VFR into IMC' event may be precipitated by loss of situational awareness due to tiredness, fatigue, workload or social pressures. Orasanu (1993, p. 22) has hypothesized that these events are more likely to "occur following schedule delays or at the end of long trips when the crew is eager to get home". She specifically suggests an underlying mechanism whereby ambiguous or discrepant information is subjectively 'normalized' or disregarded. Previous research on information processing failures in aviation accidents (O'Hare et al, 1994) has shown that errors early in the process (at the stage of diagnosing the problem, for example) are apt to have more serious consequences than errors made later in the process (e.g. handling errors).

We can investigate the differences in situational awareness that characterize problem solving early in a VFR cross-country flight compared to solving the same problem later in flight. We can also compare the situational awareness of pilots who continue a flight into IMC compared to those who discontinue the flight at the same point.

Response Selection and Risk Management: A more traditional approach to pilot decision-making has been to look at the processes by which pilots choose between various options. This is a reflection of the field of decision making in general which has developed normative (e.g. subjective expected utility theory) and descriptive (e.g. prospect theory) approaches to the choice amongst alternatives under uncertainty. The key elements in the normative approach are the end states that the decision maker believes will result from each course of action and the subjective probabilities of those outcomes occurring. A substantial body of research has demonstrated that actual decision-making does not follow the prescriptive rules very closely.

Some attempts have been made to develop models of decision making in the aeronautical context. For example, O'Hare (1992) described a framework model of aeronautical decision making (ADM) based on Janis and Mann's (1979) theory of decision making. Orasanu (1993, 1995) has described a taxonomy of decision types and described a decision process model. Two dimensions define the decision taxonomy: cue clarity and response options available. Cues can be unambiguous or ambiguous, in which case additional effort is required in diagnosis. Response options can be divided into three categories: a single prescribed response, a choice from several response options, or no prescribed response. Orasanu (1995) presents a 'decision process model' that combines the taxonomy of decision types with the kind of framework described by O'Hare (1992).

The models of ADM described by O'Hare (1992) and Orasanu (1995) both suggest a central role for risk assessment in ADM. O'Hare (1990) investigated pilot risk assessment with a variety of self-report measures and found that pilots generally underestimated the risks involved in general aviation (GA). A failure to appreciate the nature of the risks involved might explain the willingness of some pilots to 'push on' into deteriorating weather. This might reflect an underestimation of the likely effects of the hazards or an overestimation of one's capabilities to meet the demands posed by the hazards, or both.

The situational awareness and risky decision making constructs can be used to suggest alternative hypotheses as to why pilots might continue VFR flight into deteriorating weather conditions. From the situational awareness perspective, it might be that these pilots either do not notice, or do not appropriately weight the significance of the weather cues that are available to them. We can hypothesize that pilots who do not proceed with the planned flight will attach greater significance to those weather cues. From the risky decision making perspective one might hypothesize that pilots who continue the flight into deteriorating weather perceive the risks of continued flight as significantly lower than do other pilots. Alternatively, they might perceive the same degree of riskiness as do other pilots, but have a greater degree of tolerance or utility for those risks (Hunter, In preparation).

The following empirical study was designed to obtain data to directly test these hypotheses. To enhance the potential generalizability of the results we developed the highest-fidelity simulations of VFR flight that could be achieved using commercially available software and PC platforms.

Scientific and Technical Objectives: In the latest series of PC-based VFR simulator studies, the key manipulations have been of cockpit navigational equipment (GPS/no GPS), weather event onset (early/late in flight), and terrain (low altitude, coastal route/high altitude mountain traverse).

Key measured variables included pilot situational awareness (position relative to destination and other airports, state of aircraft) and situational assessment (identification of deteriorating weather cues). The pilots' assessment of risk, their decision made, and their level of flight planning and performance in actuating the flight plan, were also measured.

Onboard positioning equipment (GPS) was specifically expected to lower the pilots' awareness of the environment, as shown by their consideration of fewer options ('route myopia') as the flight progressed and the weather situation degraded. Pilots with more hours experience, or higher certification, were expected to perform better at the situational assessment task, and use the salient weather cues in their decision to discontinue the flight at an earlier, safer stage.
The risk-perception measures were exploratory. It was expected that these could be evaluated in terms of their appropriateness/relevance to the weather situation and the decision to continue or discontinue the flight.

Technical Approach: Qualified pilots were recruited from advertisements placed at the local aero club and in local newspapers. Participants were reimbursed NZ$40 after completing both experimental sessions. Eighteen pilots (15 Males, 3 Females) were recruited. The majority (15) held private pilot licenses. The remaining 3 held commercial pilot licenses. Ages ranged from 21 to 62 years (x = 37.5, sd = 13). Total flight hours ranged from 40 to 2224 (x = 295, sd = 494). Participants were randomly allocated to the GPS or non-GPS group for their flights. There were no significant differences between the groups in terms of age, total hours, total hours cross-country, hours flown in the last 90 days or cross-country hours flown in the last 90 days.

An extensive evaluation of commercially available PC flight simulators was undertaken. A PC-based flight simulator was selected (Fly!2K, by Terminal Reality) incorporating Ground Control and Sky! by Howintheworld (www.howintheworld.com) and the Flyscripts! v1.1 flight data recorder. Additions were made to the flight simulator airport database to ensure the sectional chart and simulators were as similar as possible. The program was enhanced with scenery by Peter McLean (www.flyscenery.com). This scenery is based on USGS and US Land Use data to make a highly accurate representation of terrain elevation, land use, and major geographical features. The fidelity of this scenery allows for VFR navigation with relative ease using standard aeronautical sectional charts. The aircraft modeled was a Cessna 172 SP built by

Rob Young (website.lineone.net/~r.young/) as part of his V88 series of flight model refinements. The performance of the simulated aircraft is very close to the specifications published by Cessna for this aircraft.

The computer was based around an Athlon Thunderbird 1Ghz processor with 512 MB SD100 RAM, Guillemot Hercules Prophet GeForce 2 GTS 64 MB video card, IBM 7200 rpm 30 GB hard-drive, and a Soundblaster Live! Sound card. The monitor used was a Philips Brilliance 201B 21" CRT. Pilots interacted with the simulator through a CH Products programmable Flight Sim Yoke, Hoffman Simped-Vario rudder pedals, a Precision Flight Controls programmable active link (PAL) console and a mouse. The keyboard was used for only two radio functions. The computer was set up in a cubicle to minimize distraction to the pilot.

Several questionnaires were used in this study and these can be split into three broad categories: pre-flight, flight, and post-flight.

Pre-flight: Two questionnaires were presented pre-flight comprising of demographics, flight experience, and opinions questionnaire and a lottery choice questionnaire. The demographics questionnaire was a development of that first used in our flight simulator work. The present version also incorporated relevant sections of other questionnaires found to be useful in aviation research. The lottery choice questionnaire was developed by Schneider and Lopes (1986) and was presented here in three versions, each presenting the questions in a different randomized order. The questionnaire consists of five choice problems between a monetary gamble and a sure thing of equivalent expected value. The number of times the sure thing is chosen is taken to indicate a preference towards a risk-averse style.

In-flight: The flight questionnaires were presented at pre-defined points during the experimental flights. The questionnaire used here was a development of that used in the preliminary flight simulator study. This questionnaire required pilots to answer detailed questions on the current state of the aircraft, location of airfields, terrain, weather, planning, and option and risk assessment.

Post-flight: The post-flight questionnaire was given on the completion of both experimental flights. This questionnaire covered the pilots experiences in using (or not using) the Bendix King KLN89 GPS system modeled on the simulator for navigation. This questionnaire was adapted from the original used by the CAA (NZ) to survey GPS use in New Zealand.

This experiment was run over two sessions. During the first session the pilot was required to sign an informed consent form, complete the demographic and lottery choice questionnaires, and finally complete a short training flight. The aim of the training flight was threefold: to familiarize the pilot with the flight characteristics Cessna 172 modeled in the simulator, to familiarize the pilot with navigation using the Bendix King KLN 89 GPS system, and to ensure the pilot was comfortable navigating by the sectional charts provided. The flight was approximately 25 n.m. in length and required the pilot to fly between three airports using both the GPS and traditional VFR navigation in clear weather. All controls were described and demonstrated to the pilot before they took over the simulator for the flight. Pilots were encouraged to familiarize themselves with all the aircraft and GPS functions available to them over the course of this flight. The second session began with the pilot being reminded of the procedure for the experimental flights. Written instructions, a weather report, NOTAMS, a laminated sectional chart, aircraft specifications, and all navigation equipment including a nav computer were provided at the outset. The experimenter verbally went through the all information provided for the flight and assisted the pilot in orienting themselves with the map. The pilot was informed that s/he would be flying with or without GPS depending on group allocation, and it was reiterated that the pilot was the pilot-in-command and free to conduct the flight in any way they wished.

NON-GPS GROUP: The non-GPS participants simply planned the flight, requested how much fuel they wanted for the flight and then took their seat at the simulator. The pilot was free to take whatever materials provided for the session over to the simulator for the flight. During the time the pilot was planning the flight the simulator was set up with appropriate weather and aircraft settings confirmed. Once the pilot was ready the experimenter started the simulator. A flight data recorder was activated and the GPS was turned off. For the first of the two flights the experimenter reiterated the control functions for the pilot. The pilot was then free to begin the flight. The experimenter left the cubicle and took a seat behind the pilot to monitor progress. At the pre-determined decision points or if the pilot indicated they no longer wished to continue with the flight the experimenter paused the simulation and turned off the monitor. The pilot was then invited to take a seat at a table and presented with the appropriate questionnaire. The experimenter verbally instructed the pilot to answer the questions as accurately as possible from memory, but if s/he really did not know an answer to a question to leave it blank. The pilot was also instructed that they could ask for clarification for any of the questions. While the pilot filled out the questionnaire the experimenter manually recorded the aircraft status values (airspeed, heading, etc.). Once the pilot had completed the questionnaire the experimenter checked what decision the pilot had made regarding the continuation of the flight. If the pilot chose to continue then they were instructed to take a seat at the simulator for the flight to be continued. The pilot was allowed a little time to re-orientate him/herself then the simulator was un-paused and fly on to the second decision point. If the pilot chose to do anything other than continue to the original destination of the flight the pilot was informed that the flight would be terminated at that point. The flight recorder data was saved and the simulator restarted. After a short break this procedure was repeated for the second flight.

GPS-GROUP: The procedure for the GPS group was identical to that described except for the selection and loading of waypoints into the GPS. When the pilot had finished planning the flight the experimenter asked what waypoints the pilot would like loaded into the GPS which constituted the flight plan. The pilot could select waypoints VORs, NDBs, or airports. Due to some limitations of the simulator airport database not all waypoints requested by pilots could be loaded into the GPS. If pilot selected such a waypoint then a new waypoint was identified as close as possible to the original selection to be loaded into the GPS. The pilot approved the selection of the new waypoint it was loaded into the GPS. Once the simulator was started the experimenter ran the GPS through the set-up screens and ensured it was fully operational. Once the flight recorder was activated the pilot was free to begin the flight.

FLIGHTS: Pilots were required to plan and fly two cross-country flights. The order of the flights was counter-balanced across the two experimental groups (GPS/Non-GPS) and across the participant type (GPS experience/No GPS experience).

SCUD-RUNNING FLIGHT (SR): This flight was approximately 110 n.m. in length running north to south down the Pacific coast of Washington State in the United States. The departure airport was Quillayute (UIL) and the destination was Astoria (AST) (see Figure 1). The weather forecast was for an overcast cloud base at 2000 ft AMSL with light westerly winds. The simulated weather was a cloud base of 2500 ft at Quillayute, dropping to 1500 ft after about 20 n.m. into the flight. A further weather change reduced visibility and lowered the cloud base to 800 ft 42 n.m. into the flight. If the pilot chose to continue on from this point s/he would experience further reducing visibility until about 10 n.m. from the destination. The visibility at this point was below VFR minima.

VFR-ON-TOP FLIGHT (VOT): This flight was approximately 135 n.m. long from Gansner (2O4) to Little River (O48) across the Sacramento Valley to the Pacific Coast. The first part of the flight is shown in Figure 2, following page. The weather forecast predicted fine weather over the valley but 5000-6000 ft overcast toward the coast with some lowering visibility. The weather experienced was as expected over the valley but the cloud came in further inland than expected and was sitting on top of the mountains to the west of the valley. The weather was set such that flying high across the valley to clear the western mountains would put the pilot VFR on-top of broken cloud with limited ground visibility by Decision Point 1. If the pilot chose to drop down beneath the cloud immediately s/he had to navigate very carefully through the mountains to avoid flying into cloud. If the pilot continued the flight from this point (see Figure 3, following page) then a further weather change was experienced about 15 n.m. from the destination of Little River. At this point the 6000 ft cloud layer turned solid overcast with light rain and visibility reducing to VFR minima by the time the destination was reached. Had a pilot not dropped below the broken cloud prior to the final weather change then s/he would find him/herself above a solid overcast layer.

FIG. 1. ROUTE OF THE SCUD-RUNNING FLIGHT

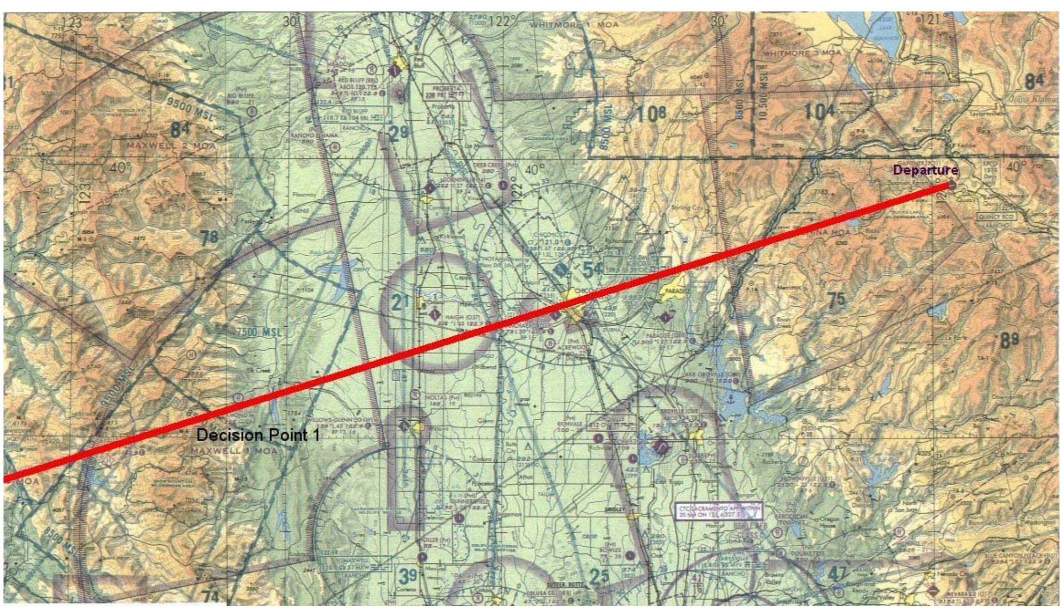

FIG. 2. ROUTE OF THE VOT FLIGHT, PART ONE

FIG. 3. ROUTE OF THE VOT FLIGHT, PART TWO

FIG. 4, SCENES FROM THE VOT FLIGHT. Approaching the Mountains (left) and Flying On-Top of Broken Cloud (right)

<u>Results</u>: The first section of the results reports the analyses comparing the characteristics and responses of those pilots who elected to continue flights past the first decision point with the characteristics and responses of those pilots who elected to discontinue the planned flight at the same point. The second section contains the analyses comparing the characteristics and responses of those pilots in the GPS condition with those in the non-GPS condition.

SECTION ONE, FLIGHT CONTINUATION:

RISK-PERCEPTION, ANXIETY, AND IN-FLIGHT DECISIONS: In evaluating the relative risk involved in each of the 5 possible decision options, participants who opted to continue on the VOT flight rated the continuation option as significantly less risky on a 10-point scale than did those who chose to discontinue the (3.75 vs 8.20; $F(1)=15.457$, $p=.001$). Also of interest is the difference on the option to ‘return to the airport of departure’ (2.38 vs 4.8); $F(1)=4.290$, $p=.055$), and the fact that the continuing group saw this option as the least risky of all five options. Treating the five options as a multivariate measure of risk perception also supports the idea that, to the continuing group, all of the possible decision options appear less risky ($F(5)=3.015$, $p=.059$). The same pattern emerges in the SR flight, although the continuing group in that flight was very small (n=3). Participants who opted to continue on the SR flight rated the continuation option as significantly less risky on a 10-point scale than did those who chose to discontinue the flight (4 vs 8.57; $F(1)=11.155$, $p=.004$). Taken as a multivariate measure these ratings also indicate a marginally significant effect on the perceived riskiness of all five options as a group ($F(5)=2.7$, $p=.083$). The continue group rated the options collectively less risky than their non-continuing counterparts. Non-continuing pilots seem more likely to go with the option they perceive to be least risky. On the SR flight 1 out of 3 (33%) continuing pilots, compared with 11 out of 14 (79%) non-continuing pilots, chose their lowest risk option (Fisher’s Exact $p=.085$). On the VOT flight approximately equal proportions (38% continuers and 60% non-continuers) chose their lowest risk option. In other words, approximately two-thirds of continuing pilots on both flights do so despite having identified a lower risk alternative.

MOOD: In each flight the most direct measure of mood at the first decision point was the question “How comfortable were you with the situation when the simulator was stopped?” (emphasis added), inviting responses on a 1(Very Comfortable) to 10(Very Uncomfortable) scale. On both the VOT flight (4.88 vs 7.1; $F(1)=3.601$, $p=.076$) and the SR flight (4 vs 7.4; $F(1)=5.705$, $p=.031$) the continue group was more comfortable than the non-continue group.

COSTS AND BENEFITS: Pilots were asked to generate a list of the potential costs and benefits associated with each of the specified options at Decision Point 1. These lists were coded by first counting the number of items generated for each option. The items were then weighted according to their severity or importance on a scale from 1 (Not very important, e.g., minor time or financial cost, inconvenience or advantage) to 5 (Very important, e.g., life or death consequences). Only one option in particular revealed a significant difference between the continuing and non-continuing groups – on the SR flight the continuing group identified marginally more weighted benefits of the option to make a precautionary landing at the nearest airstrip, $F(1)=3.295$, $p=.09$. On the VOT flight, the non-continue group identified significantly more costs and benefits for almost all of the options, with one tie. A sign test gives $p(X(9)=1)=.02$. On the SR flight the non-continue group also identified significantly more costs and benefits [$p(X(10)=1)=.011$]. Taking the weightings into account, the non-continue group identify more weighted costs or benefits on 7 out of 10 options on the VOT flight (ns), and on 8 out of 10 options on the SR flight [p(X(10)=2)=.055].

PROS AND CONS: Combining the benefits associated with a particular pilots choice with the costs associated with the options the pilot disregarded, gives an estimate of the ‘Pros’ a pilot might be considering in favor of the option they chose. Conversely, the average benefit of the options not chosen, and the costs identified with the choice, can be viewed as the ‘Cons’ of the option chosen. A similar calculation gives the ‘Pros’ and ‘Cons’ associated with the hypothetical option to continue the flight (hypothetical, because not every pilot took that option). Interestingly, the non-continuing pilots on both flights identify more pros and cons of both the option they actually chose and the option to continue the flight, than the continuing group did. This overall pattern remains the same whether the simple or weighted counts of costs and benefits are considered. Only one of the differences turns out significant in its own right – on the VOT flight, the non-continue group identified more ‘Pros’ for the choice they actually made than the continue group identified for theirs [F(1)=8.4, p=.012].

EXPECTATIONS ABOUT ROUTE:

TERRAIN:

Maximum Terrain Altitude… (feet)	**VOT Flight Group, DP1**	
	Continue	**Non-Continue**
Expected to Course of Action	6185.71	4577.78
Actual to Course of Action	5285.71	2000.00
Accuracy to Course of Action	+900.00	+2416.67
Expected to Original Destination	6185.71	7012.50
Actual to Original Destination	5285.71	5750.00
Accuracy to Original Destination	+900	+1262.50

Table 1. Expected and Actual Maximum Terrain Altitudes for VOT Flight, Decision Point 1

After the first decision point on the VOT flight, the continue group were traveling over significantly higher terrain (enroute to the originally planned destination) than the non-continue group (enroute to whichever alternative they had selected (continue 5285 feet vs. non-continue 2000 feet, F=8.96, p=.012). Whilst both groups overestimated the maximum terrain altitudes they would encounter (either enroute to the originally planned destination, or enroute to the chosen alternative), the continue group had slightly lower and more accurate expectations, although these difference in altitude and accuracy are not significant.

Maximum Terrain Altitude… (feet)	VOT Flight Group, DP2	
	Continue	**Non-Continue**
Expected to Course of Action	1540	6000
Actual to Course of Action	750	3000
Accuracy to Course of Action	+740	+3000
Expected to Original Destination	1540	6500
Actual to Original Destination	750	3000
Accuracy to Original Destination	+740	+3500

Table 2. Expected and Actual Maximum Terrain Altitudes for VOT Flight, Decision Point 2

At the second decision point on the VOT flight, 6 pilots elected to continue to the original destination, whilst 2 decided to divert to their nearest alternative. Once again, the continuing group gave lower (1540 feet vs 6000 feet; $F=36.193$, $p=.004$), more accurate estimates (+ 740 feet vs + 3000 feet; $F=7.56$, $p=.051$) of the maximum terrain altitudes they expected to encounter on their course of action. The continue group also saw the terrain to the originally intended destination as being lower than the non-continue group (1540 feet vs. 6500 feet; $F=44.763$, $p=.003$).

Of the three pilots who elected to continue on the SR flight, only two navigated successfully to the second decision point, and from there both intended to complete the flight as originally planned. While comparisons are inappropriate, these two pilots did give highly accurate estimates of the terrain (or lack of) that they expected to encounter. The coastal terrain may have simplified this task – there is little between the two pilots and their destination, by the second decision point, but water.

IMMEDIATE GOALS AND WEATHER: Pilots were asked at the first decision point to state their most immediate goals with respect to flying their intended course of action. The responses to this were widely varied, although they could be considered to fall into three general categories. Weather-related statements included mentioning the current or expected weather the pilot would experience, or outlining weather-related contingencies, such as “Continue as planned, unless weather deteriorates”. Non-weather statements included references to the safety of the flight that were not specifically weather related, such as maintaining minimal altitudes, statements about the terrain, and so on. A third category captured all Other goals, such as references to airports, waypoints, and routes to be taken. On the VOT flight the two groups (continue/non-continue) emphasized different categories in stating their immediate priorities. In outlining their immediate goals at the first decision point, the continue group on the VOT flight made more specific references to weather or weather-related contingencies than the non-continue group [$F(1)=8.169$, $p=.011$]. The continue group on the SR flight also make more specific mention of weather in stating their immediate goals, although the difference is not significant. In a within-groups comparison, the continue group made more Weather-related statements than they did Non-weather (Z=-2.251, p=.016). The non-continue group, on the other hand, made more mention of Other goals than either weather-related (Z=-1.807, p=.063) or Non-weather VFR (Z=-1.852, p=.043). On the SR flight the continue group showed essentially the same emphasis on Weather-related statements over Non-weather VFR statements, although the difference was not significant.

MODIFICATIONS TO FLIGHT PLAN: Pilots were asked to indicate if they had made any further modifications to their flight plan after they had decided on a course of action. Only 1 out of 8 continuing pilots indicated that they had further modifications to make to their flight plan following the decision point, compared to 6 out of 10 non-continuing pilots (Fisher's Exact p=.066).

DECISION CUES:

Name of Cue	**VOT Flight Decision**		**SR Flight Decision**	
	Continue	**Non-Continue**	**Continue**	**Non-Continue**
Cloud Base Characteristics	6.50	6.50	**9.33**	7.71
Horizontal Visibility	6.13	**6.80**	**9.00**	8.36
Darkened Cloud	2.38	**5.10**	**7.33**	4.79
Increasing Cloud Concentration	7.38	**8.11**	3.33	**7.64**
Rain Showers	2.63	**4.90**	3.33	**4.79**
Distance Between Cloud Base and Horizon	**6.13**	5.60	**9.00**	6.93
Cloud Type	5.38	**5.40**	**7.67**	5.64
Wind Direction	1.88	**3.90**	**5.00**	4.93
Wind Velocity	2.13	**4.70**	**5.00**	4.64
Cloud Proximity to Aircraft	6.25	**6.60**	**9.33**	7.71

Note: Bold typeface indicates greater importance on 10-point scale ranging from 1 (Not at all Important) to 10 (Very Important).

Table 3. The Importance of Weather Related Cues at the First Decision Point.

In their appraisal of the importance of specific weather-related decision cues at decision point 1, the continuing group on the VOT flight rated 8 of the 10 cues as less important than the non-continue group, with a tie on one of the cues. Whilst none of the differences were significant in themselves, a sign test of this overall pattern gives p(x(9)=1)=.02, indicating that the continuing group rated the cues as less important than did the non-continue group. This pattern was reversed on the SR flight, however, with the continuing group rating 8 out of 10 cues as more important, p(x(10)=2)=.055).

DEMOGRAPHICS, BACKGROUND EXPERIENCE, AND SELF-RATINGS:

FLIGHT-HOURS AND RECENT EXPERIENCE:

Experience Measure	VOT Flight		SR Flight	
	Continue	Non-Continue	Continue	Non-Continue
Age	36.88	38.20	43.00	36.53
Total Hours	197.51	167.86	257.20	165.66
Hours as PIC	100.00	78.41	184.50	64.95
Hours in Last 90 Days	18.89	8.42	25.37	10.15
Hours Cross-Country	48.69	32.29	117.25	27.75
Hours Cross Country in Last 90 Days	6.60	1.18	9.50	2.05

Table 4. Experience and In-Flight Decisions at the First Decision Point on Each Flight

Pilots were asked to indicate (and substantiate, using flight logbooks or other evidence) their total hours of flight experience. They were also asked, of those hours, how many were as Pilot-in-Command (PIC), how many involved cross-country flying, and how many had been logged in the previous 90 days (and of those, how many were specifically cross-country hours in the last 90 days).
On each flight, the group who opted to continue were those with more experience overall, and more recently logged experience in particular. A MANOVA of the 5 experience aspects suggests that more experience is an important predictor of the decision to continue on the SR flight, F(5)=20.976, p=.002. Whilst the pattern was the same on the VOT flight (consistently higher hours in all 5 aspects), the overall difference was not significant.

On the VOT flight, the continuing group had logged significantly more hours of cross-country flight in the previous 90 days, (6.6 hours vs. 1.18 hours; F(1)=4.9, p=.047). The continuing group had more than twice as many total hours in the previous 90 days, although this difference was not significant. On the SR flight the continuing group had logged significantly more hours of flight in the previous 90 days, (25.37 hours vs. 10.15 hours; F(1)=3.96, p=.068). This figure included also 7.45 hours more cross-country for the continuing group, although the difference was not significant.

PERSONAL MINIMUM FLYING REQUIREMENTS: On the VOT flight, the continue group indicated that they would undertake a daytime cross-country flight with a lower minimum visibility than the non-continue group (10km vs 15km; $F(1)=4.8$, $p=.044$).

SELF-RATINGS: Pilots completed a variety of self-ratings, including appraisal of their own skills (relative to other pilots of a similar experience level), attributes (such as cautious, careful), and likelihood of being involved in an accident. The continue group on the VOT flight agreed more strongly with the statement "I am a very careful pilot"(5.00 vs 4.50; $F(1)=3.95$, $P=.064$). When asked to estimate their risk of being involved in an accident in the next 10 years (given an average flight time of 100 hours per year) the continuing group placed themselves in a higher risk band on a 6 point scale from 1/10 to 1/1 000 000 (rising in powers of 10). The continue group rated their own risk likelihood at 1/1 000, with the non-continue group at 1/10 000 [$F(1)=6.5$, $p=.021$]. Both groups considerably underestimate the actual risks which are closer to 1 in 10 (O'Hare, 1990).

RISK-PROPENSITY AND DECISION MAKING: Lopes (1987) has proposed that people can be characterized in terms of their opportunity seeking (risk seeking) or security-seeking (risk averse) disposition. Schneider and Lopes (1986) measured participant's preferences between a series of five monetary choices involving a sure thing and a gamble of equal expected value. The greater the number of choices for the sure thing, the higher the individual's risk-aversion or security seeking. Across the two flights, 9 participants elected to continue past the first decision point on at least one occasion whilst the other 9 elected to discontinue the flight at the first decision point in both flights. There was no difference in the lottery risk scores between the two groups. The correlation between lottery risk score and performance in the flight scenarios was essentially zero ($r = -.043$). According to Schneider and Lopes (1986) the lottery risk survey yields a highly skewed distribution of responses with 70% selecting the sure thing at least 4 times and only 1% selecting the sure thing fewer than 3 times. In the present sample, the corresponding figures were 78% and 5.5% respectively.

USUAL AERONAUTICAL PRACTICES (UAP):

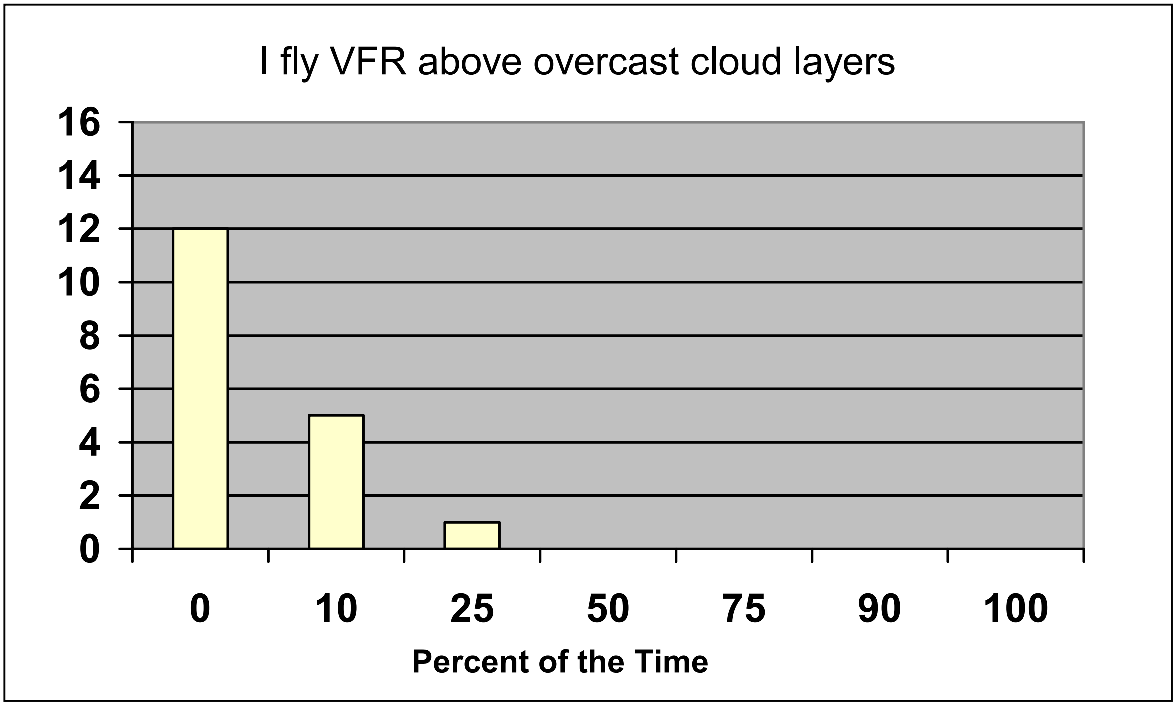

Fig. 5. Responses to Usual Aeronautical Practices Question Regarding VFR Flight ‘On-Top’

Pilots were asked to estimate their adherence to a variety of aeronautical practices. Of note, 12 pilots indicated that it was their practice never to fly VFR above an overcast cloud layer. Six (50%) of these pilots subsequently elected to continue the VOT flight at the first decision point, most flying some distance above solid overcast as a consequence. Responses to the other UAP measures are summarized in Appendix One.

SITUATIONAL AWARENESS:

CONFIDENCE IN POSITION:

On the SR flight the non-continue group reported that they were more confident in their current position than the continue group (9 vs 6, on a 1(not at all confident) to 10 (extremely confident) scale); $F(1)=23.4$, $p<.001$). This pattern was reversed in the VOT flight, with the continue group expressing greater confidence (9.3 vs 6.1); $F(1)=5.9$, $p=.029$).

TIME ESTIMATION

Time (Minutes)	VOT Flight Decision		SR Flight Decision	
	Continue	Non-Continue	Continue	Non-Continue
Estimated Time Elapsed	51.29	50.10	37.00	24.00
Actual Time Elapsed	54.50	54.50	28.33	26.92
Accuracy[1]	-2.14	-4.40	8.67	-2.92
Absolute Accuracy	6.71	5.00	9.33	3.23

1: Negative integers reflect under-estimation of elapsed time.

Table 5. Time Estimation and In-Flight Decision at the First Decision Point

On both flights, the non-continue group gave a lower and more accurate estimation of the time elapsed on the simulator by the first Decision Point. On the VOT flight these differences were not significant. On the SR flight, however, the difference was quite marked, with the continue group estimating a time 12.86 minutes longer than the non-continue group (F(1)=7.16, p=.017). In absolute terms, the non-continue group was also significantly more accurate, their estimates being 6.1 minutes closer to the actual time elapsed than the continue group (F(1)=4.491, p=.052).

POSITION AT FIRST DECISION POINT:
Allowing the pilots complete autonomy over the planning of their cross-country flights led to a wide variation in locations by the first Decision Point on each flight. On the VOT flight, non-continuing pilots had reached a point that was marginally further west (towards the destination) than continuing pilots. This difference, whilst small, is of note as the weather on the VOT flight deteriorated, and the terrain rose, as the pilots pressed westward. Pilots who had flown further by the first decision point may have been more aware of inclement weather, and treacherous terrain, and therefore been more inclined to discontinue the flight (although this is not reflected in their estimates of visibility, or the actual visibility in which they were flying).

In the SR flight, on the other hand, the continuing pilots were following a course that took them further west than the non-continue pilots. When the simulator was stopped, the average continuing pilot was at Longitude W12414’11” whilst the average non-continue pilots was at W12413’35” (F=18.615, p=.002). This is interesting for a different reason than on the VOT flight, as the course of the SR flight was North-South. Although the difference is small (approximately 1 nautical mile) the more westward track of the continuing pilots was likely to keep them flying over lower coastal terrain, or over water, so that the lowering cloud at the first Decision Point may have appeared slightly less threatening. In two cases, this low-flight-over-water option turned out disastrously. In one case the pilot lost altitude during a turn, and in the other the pilot allowed the aircraft to descend whilst their attention was briefly directed toward the GPS – both aircraft crashed into the sea.

SECTION 2, GPS VS NON-GPS

EFFECTS OF GPS ON DECISION MAKING:
The decisions made at each of the two decision points in each flight are tabulated below. Every pilot, except one, reached the first decision point (DP1) in each flight. The single exception was a pilot in the non-GPS condition in the scud-running flight who was turning back towards land having strayed too far out to sea. In the process, he lost altitude and crashed into the sea.

	Scud-Running Flight				VFR On-Top Flight			
	GPS		No GPS		GPS		No GPS	
	DP1	DP2	DP1	DP2	DP1	DP2	DP1	DP2
Continued	3	2	0	0	4	3	4	3
Precautionary	1	0	4	0	1	1	1	1
Divert	1	0	1	0	4	0	1	0
Return	4	0	3	0	0	0	0	0
Orbit	0	0	0	0	0	0	3	0
Crashed	0	1	1	0	0	0	0	0

Table 6. Decisions Made by GPS Groups at Each Decision Point on the Two Flights

These data indicate some potential differences between the GPS and non-GPS conditions in the two flights. In the scud-running flight, all three pilots who continued past the first decision point were flying with the aid of GPS. A Chi test of the difference between the two groups for continuing/not continuing was marginally significant ($\chi(1) = 3.2$, $p = .07$). Similarly, almost all the pilots who elected to carry out a precautionary landing were in the non-GPS group ($\chi(1) = 3.1$, $p = .079$). Taken together, the results are indicative of a greater tendency for the GPS group to press-on or remain airborne than the non-GPS pilots. Whilst there was no difference in the tendency to continue past the first decision point in the ‘VFR on top’ flight, the only pilots who elected to ‘orbit were all in the non-

GPS group ($\chi(1) = 3.6$, $p = .058$). There were no differences in option choice at the second decision point (DP2) in this flight between the GPS and non-GPS groups.

DECISION CUES

In the weather related cue appraisal, the GPS group rated 9 of the 10 cues as more important than the non-GPS group on the VOT flight. A sign test gives $p(X(10)=1)=.011$. Of these 9 cues, 2 were individually rated as significantly more important: “Cloud Base Characteristics” (8.56 vs 4.44, $F=6.39$, $p=.022$), and “Horizontal Visibility” (8.33 vs 4.67, $F=4.481$, $p=.05$). On the SR flight the GPS group identified 5 of the10 cues as more important. None of the differences were significant.

DISCUSSION: The main focus of the study was on the decision to continue a cross-country VFR flight once deteriorating weather conditions had been encountered. Two simulated cross-country flights were constructed to reflect commonly occurring weather situations. One flight involved flying underneath an overcast sky with progressively deteriorating ceiling and visibility. The other involved an encounter over mountainous terrain with a broken cloud layer beneath the aircraft which gradually became a solid layer. Pilots were instructed to plan and fly the flights as they normally would in an aircraft. Half of the participants used a simulated GPS navigation tool and the other half flew using their own dead reckoning. At pre-determined decision points, the simulations were frozen and a range of measures of risk assessment and situational awareness were taken. The principal findings were as follows.

EXPERIENCE: Continuing pilots were slightly more experienced overall, and had substantially more flight experience in the previous 90 days. Recent flight experience has been shown to be a predictor of decision-making in simulated flights (e.g. O’Hare, 1990) and a predictor of accident involvement in real crashes (e.g. O’Hare, 1999).

SITUATIONAL ASSESSMENT: Continuing pilots made more mention of the weather in outlining their immediate goals at the first decision point than non-continuers. Continuing pilots also made more weather-related statements than they did non-weather-VFR-related statements (at a ratio of 5 to 1, on the VOT flight) or other-related statements (approximately 2 to 1, on both flights). The implication seems to be that continuing pilots are fully aware of the weather: they clearly perceive it to be deteriorating and yet, at the same time, non-threatening.

RISK PERCEPTION AND MOOD: Continuing pilots seemed to perceive the two scenarios as less risky overall (including their appraisal of options they have disregarded), and were more ‘comfortable’ when the simulator was stopped at the first decision point. These are both possible indicators of a less anxious or more optimistic state of mind. The tendency of the continuing group to consistently under-estimate (relative to non-continuers) the risks inherent in each option might speak to a globally more optimistic, or less anxious, state of mind accompanying the decision to continue. The feeling seems to be clearly either “This flight can continue and everything (including the disregarded options) is hunky-dory” or “This flight cannot continue and everything (including all alternatives to continuing) is somewhat bleak”. This is also consistent with numerous findings that increase in anxiety lead to, or are accompanied by, increased perception of risk or threat in the environment (e.g., Gasper & Clore, 1998; Stoeber, 1997; Hellesoy, Gronhaug & Kvitastein, 1998), especially when the source of the anxiety is relevant to the risk-assessment domain (Constans, 2001). There was also a clear indication on both flights that the continuing group was more comfortable with the situation when the simulator was stopped. In the present study, this is the nearest approximation to a measure of mood that was employed. When viewed in conjunction with the heightened risk-perception, this pattern is consistent with an effect of increased anxiety on the pilots who opted to discontinue the flight. Raghunathan & Pham (1999), for example, found that state-anxious individuals would consistently choose a low-risk/low-return gamble, even if couched in a variety of different guises. In this case involving the appraisal of options in a dynamic simulation in the face of deteriorating weather, those who are less comfortable are choosing options that they perceive to be less risky, despite their implication of lower returns (such as not making it to planned destination). Contrariwise, pilots at higher comfort levels have a return-maximizing strategy, taking the option with the highest return (continuing to originally planned destination), despite their own perception that it is not always the safest option.

DECISION MAKING AND MOOD: The decision to continue appears to be almost a case of making no-decision-at-all. Pilots who continue indicated fewer modifications to their flight plan once the decision is made. They also suggest fewer costs or benefits of the various options, and find fewer ‘pros’ in support of their decision than the non-continue group. The non-continue group, on the other hand, generated more costs and benefits, and more pros and cons, for both the option they chose and the option to continue. Thus it seems that more thought is put into the decision to discontinue the flight than into continuing it. This also seems to be consistent with known effects of anxiety, or negative affect, on the decision making process. Participants in a more anxious (decreased comfort) state seem to be using a more analytic, bottom-up, approach, as evidenced by their generation of more elemental items of cost and benefit across the board. Conversely, pilots in a non-anxious (undisturbed comfort) state may process the situation in a more holistic, or top-down, manner. No cues, or combination of cues, have registered as particularly significant, so their approach is one of unconflicted adherence (to use the terminology of Janis and Mann, 1979) to their original flight plan. These findings are similar to those of, for example, Bless & Fiedler (1995), where mood manipulations saw happy and sad participants engaging in different information processing strategies (happy participants using heuristic, ‘general-knowledge’ structures, sad participants using an analytic, ‘information conserving’ approach).

CONCLUSION: The study was designed to illuminate the question of whether the decision to extend a cross-country flight onwards into deteriorating weather conditions is primarily due to poor or inaccurate situational awareness or due to risk assessment or risk taking in some form. A secondary aim was to gather performance data on the effects (if any) of using a GPS navigation system on performance, situational awareness and risk assessment and risk taking in simulated VFR flight. There was little support for the situational awareness perspective in this study. Those pilots who chose to continue their flights after encountering deteriorating conditions were clearly aware of the changed conditions but remained untroubled by the deterioration. These pilots viewed the option to continue the flight as markedly less risky than the non-continuing pilots whilst at the same time perceiving themselves more strongly as careful pilots. The majority of pilots who continued did not rate this as the lowest risk option available to them indicating a degree of risk taking. However, they did not perceive themselves to be greater risk takers than the non-continuing pilots when asked to explicitly rate this. The continuing pilots were also a little more experienced overall with significantly more recent flight hours in the previous 90 days.

The most significant finding was that the non-continuing pilots exhibited signs of feeling significantly less comfortable with the situation. This was reflected in explicit ratings of comfort as well as in a generalized elevation of risk ratings for all the available options. The non-continuing pilots also engaged in more reflection on the pros and cons of the various options. These effects are consistent with a growing body of research showing that negative affect (e.g. anxiety) increases the perception of risks and encourages a more deliberative style of decision making. The present study is unable to provide any evidence on the question of whether the increased discomfort/anxiety exhibited by the non-continuing pilots was a cause or a consequence of their decision-making. The role of these affective processes in aeronautical decision-making deserves further investigation. In order to better describe the results obtained in the present project as well as earlier flight simulation studies of VFR cross-country decision making (Owen, 2000) a simplified theoretical framework can be proposed. The key elements of the model are as follows:

1. Pre-existing dispositions. Research into individual differences has established that individuals vary along numerous dimensions such as, sensation seeking (Zuckerman, 1979), trait anxiety (Spielberger, Gorusch, & Lushene, 1970), extraversion (Eysenck, 1967), conscientiousness (Costa, 1996) etc.
2. Training and experience may exacerbate or moderate these initial predispositions. For example, a chronically nervous individual may become even more apprehensive after spin training and form a strong aversion to anything other than straight and level flight. In contrast, a high sensation-seeking individual might develop an attraction for aerobatics as

a consequence of the same experience. In either case, pilots develop beliefs about their aptitudes and abilities. Experience can easily lead to false impressions of ability to cope as when a pilot successfully deals with flight in marginal conditions.

3. Knowledge is organized in mental structures referred to as schemas, frames or scripts. Flight related knowledge is probably stored in schemas related to typical sequences of events (Schank & Abelson, 1975) such as 'takeoffs', 'cross-wind landings' and so forth. These schemas encapsulate the pilot's knowledge about such events garnered from personal and vicarious experience (Schank, 1999).
4. There is increasing evidence that internal affective states have an important influence on decision-making and judgment (e.g., Forgas & George, 2001). The pilot who develops an aversion to spins, for example, will experience distinct physiological changes before and during such an event. The effects of anxiety on risk perception have been discussed previously. A pilot may start to feel worried or concerned before any explicit recognition of danger has been formulated. In the context of driving, Groeger (2000, p. 141) has suggested that "The determination that something is or is not dangerous proceeds…from a rather unspecific feeling".
5. There is evidence to support the view that reactions and responses to objects and events can be determined by implicit processes not accessible to conscious awareness (Greenwald & Banaji, 1995). As yet, no studies of implicit processes have been reported in the field of aeronautical decision-making. Nevertheless, it is quite possible that implicit associations to objects and events are formed during training and subsequent experience.
6. Encounters with flight events and their associated cues are compared to representations of those events retrieved from memory. Such memory comparisons are the central feature of recent naturalistic models of decision making (e.g. Klein, 1989). If a good match can be found then the action implications of the event can be directly retrieved, and the decision making process is completed without analytical deliberation. This is the 'reflexive' path in the model. Experts, with a more extensive and better-organized knowledge base are more likely to access appropriate representations in memory (Stokes, Kemper & Marsh, 1992).
7. If the comparison between the current event and representations retrieved from memory does not result in a successful 'match' then the pilot will engage in more deliberative, analytical decision making. This is the 'reflective' path in the model. Such deliberation can take many forms involving various different processes. Engaging in more intensive processing may increase anxiety and arousal levels (Miller, 1987). Ironically, the novice pilot who may be driven towards greater reliance on deliberative or reflective decision making processes by increased levels of anxiety or arousal, may now find their anxiety and arousal levels increased further as a result.

Impact/Applications: The model described below (See end of Section 9 - Results) is fully consistent with the results obtained from our flight simulation study and is supported by a wide range of empirical evidence from other fields of psychology and cognitive science. The strongest effects in the data (described in Section 9 - Results) concern the role of implicit and affective processes in risk assessment and style of decision making. As a result of the flight simulation study we propose to focus our efforts more intensively on this issue. We have developed a second set of simulated cross-country flights using Microsoft Flight Simulator 2002. This offers superior terrain detail to that used in the study described above. We intend to have pilots fly the same scenarios used for the present study but in the reverse direction. In the next study, pilots will encounter 'VFR on top' conditions early in the VOT flight and the reduced ceilings and visibility will occur much later in the SR flight. Comparisons across the two studies will enable us to resolve the question of whether the timing of the encounter (i.e. duration into flight) with weather-related events affects decision processes and outcomes. We will also institute a much wider range of measures of mood and affective responses. We are considering the investigation of external factors such as time pressure on the decision-making processes of experienced and novice pilots.

Technology Transfer: none

Journal Articles:

O'Hare, D., & Owen, D. Cross-country VFR crashes: pilot and contextual factors. Aviation, Space, and Environmental Medicine. XXX. (2002).

Wiegmann, D.A., Goh, J., & O'Hare, D. (In press). Aeronautical decision making: Effects of distance traveled on pilots' decisions to continue visual flight rules (VFR) flight into adverse weather. Human Factors.

Books or Chapters: none

Technical Reports: none

Conference presentations/abstracts:

O'Hare, D., Owen, D., & Wiegmann, D. The 'where' and the 'why' of cross-country VFR crashers: database and simulation analyses. In Proceeedings of the Human Factors and Ergonomics Society 45th Annual Meeting. Santa-Monica, CA: Human Factors and Ergonomics Society (CD-ROM).

Patents Issued or Pending: none

Honors: none

Related Projects: Learning from experience: The role of aircraft accident and incident case histories in aviation safety and training. Research Grant NAG2-1395 from NASA-Ames Research Center, Moffett Field, CA.

Appendix II

Human Factors General Aviation Research Requirements

Research requirements exist in the AAR-100 interactive management database that allows program managers to track research requirements for each Federal Aviation Administration sponsor.

Requirement ID: 3

Sponsor Organization: ACE POC: Jeff Holland

Requirement Title: CFIT/Terrain displays

Funded Requirement:
- FY01: Yes
- FY02: Yes
- FY03: No
- FY04: No

Requirement Statement: The purpose of this research is to address CIT issues which were identified by the JSIT team. Research will focus on various countermeasures to include training, technology, and science-based regulations to significant reduce the occurrence of general aviation CFIT accidents.

Background: Controlled flight into terrain (CFIT) accidents have been cited as one of the leading causes of fatalities for general aviation (GA) flyers. A CFIT accident occurs when an airworthy aircraft, under control of a pilot, is flown into terrain, including water or obstacles, with inadequate awareness on the part of the pilot of the impending accident. In response to the high rate of occurrence and fatalities, the FAA formed a Joint Safety Analysis Team to investigate the causes of GA CFIT accidents. The team analyzed over two hundred reported CFIT accidents for a two-year period (1996-1997). The team identified numerous casual factors that contributed to the occurrence of the accidents. Considering these casual factors, the team developed 55 intervention strategies that had some potential to mitigate the casual factors. One of the most effective strategies identified by the team was the installation and use of horizontal and vertical situation awareness displays.

Manufacturers have been developing and marketing horizontal and vertical situation awareness displays for quite some time. The quality of the displays varies significantly. However, with the more recent advent of less expensive and higher quality color displays, there has been a significant increase in the quantity and sophistication of these systems. Unfortunately, the designs seem to be more driven by intuition, supposition and marketability than by data. The effectiveness of some of these systems to prevent CFIT accidents is at best questionable.

Research needs to be conducted to determine the minimal amount and type of information that should be presented to develop adequate situation awareness to avert CFIT related accidents. There are a number of key issues that need to be addressed:

Horizontal Situation Displays versus Vertical Situation Displays versus Both

Benefits/Detriments for 2-D & 3_D Displays

- Minimum Display Size
- Minimum Level of Detail and Quality of Terrain Depiction,
- Type and Form of Displayed Position-Terrain Information
- Color Application Philosophy (darker colors for lower elevations),
- Desired Visual/Audio Alerts.
- Most Appropriate and Effective Cues to Alerting Pilot of an Impending Situation
- Methods of Operation
- Appropriate Use of Such Systems

The information from this research could be used by the CFIT JSIT to weigh and prioritize implementation strategies. It could also serve as "best practices" guidance to manufacturers of position-terrain awareness systems, it could provide a measure to compare new systems against in terms of best practices and undesirable features.

Output: none

Regulatory Link:

1. AOA (FAA) Strategic Plan (1998-2003) - Mission Goal: Safety. By 2007, reduce U.S. aviation fatal accident rates by 80 percent from 1996 levels (pg. 13). Focus areas: Accident Prevention, General Aviation Initiative addresses CFIT, weather, runway incursions, loss of control, and decision-making (pg. 14).
2. FAA FY2000 Performance Plan - Reduce the General Aviation Fatal Accident Rate (pg.16).
3. AVR Performance Plan - Goal B-1, reduce fatal aviation accident rate attributed to human error.

Requirement ID: 4

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Pilot field-of-vision capabilities/limitations

Funded Requirement:
- FY01: Yes
- FY02: No
- FY03: No
- FY04: No

Requirement Statement: The research objectives of this requirement is to develop human factors recommendations to assist in alleviating pilot error and increased pilot workload created by non-standard installations of avionics devices and other cockpit equipment in general aviation aircraft. The research will provide pilot field-of-vision limitations for design considerations.

Background: Update of field-of-view data with the express purpose of defining display location boundaries that correspond to established desing eye positions for GA aircraft. Existing guidance is based upon the head held in an erect fixed position, which is not representative of actual operation. New data needs to be generated based upon realistic head position. Also data must be gathered in a context of actual operational tasks and constraints, to address more than just physiological considerations. Degraded modes of operation should also be considered.

This research is sorely needed to provide human factors recommendations to assist in alleviating pilot error and increased pilot workload created by non standard installations of avionics devices and other cockpit equipments.

Output: A reduction in pilot error and alleviation of pilot workload resulting from improved installation considerations of and interaction with various cockpit devices.

Regulatory Link:
1. AOA (FAA) Strategic Plan (1998-2003)-Mission Goal: Safety. Supports the DOT Strategic Goal of Safety. Key Strategies include Research to study issues and technologies (especially Human Factors) to improve policies, procedures and equipment (pg.13). It also supports the Focus Area of Accident Prevention by addressing Flight crew/vehicle interface and interaction issues (pg. 15)
2. FAA FY2000 Performance Plan-Reduce the General Aviation Fatal Accident Rate.
3. AVR Performance Plan-Goal Targeting Performance Areas "Contribute to aviation safety by developing policies and/or standards, programs, and

systems to reduce the number of aviation accidents and incidents related to Human Factors."

Requirement ID: 5

Sponsor Organization: AFS-800/ACE POC: Michael Henry and Frank Bick

Requirement Title: Causal factors of accidents and incidents attributed to human error

Funded Requirement:
- FY01: Yes
- FY02: Yes
- FY03: Yes
- FY04: Yes

Requirement Statement: This requirement objective is to identify potential data sources to identify causes of general aviation human error accidents as well describe potential remedies. The outcome of the research should be to develop and standardize methodologies for identifying, defining, and monitoring human error based incidents and accidents.

Background: Causal factors of human error: Intent is to provide better recording of human factors aspects of accidents so that subsequent analyses can more accurately depict the true underlying causal factors.

Output: Develop and validate a standardized methodology for conducting accident investigation in which human error is cited as the cause or contributor to the accident. This effort must produce a product that does a much better job in the assessment of incidents attributable to human error in the cockpit/flight deck.

Regulatory Link:
1. Supports Safer Skies through Areonautical Decision Making (ADM) JSAT
2. AOA (FAA) Strategic Plan (1998-2003) Mission Goal:Safety. Key Strategies "to enable the goal to include identification of root causes of past accidents; and (2) use a more proactive analytical approach, with new data sources, to identify key risk factors and intervene to prevent potential causes of future accidents" (Page 13).
3. FY2001 Performance Plan: Focus Area: Accident Prevention. "Aviation Human Factors to coordinate human factors research, development and based on detailed causal analysis" (Page 2)
4. AVR Performance Plan:Reduce General Aviation fatal accidents (pg 2). Contribute to aviation safety by developing policies, standards, programs, and systems to reduce the number of aviation accidents and incidents related to human factors (pg 9)

Requirement ID: 15

Sponsor Organization: AFS-800 POC: Michael Henry

Requirement Title: Loss of Primary Flight Instruments during IMC

Funded Requirement:
- FY01: Yes
- FY02: No
- FY03: No
- FY04: Yes (new requirement will be submitted)

Requirement Statement: This requirement objective is to identify the probably pilot response to loss of primary flight instruments during IMC and provide recommendations to significant reduce the potential of accidents and incidents. Research should identify training, technology or regulatory solutions.

Background: Most single-engine general aviation airplanes are not equipped with redundant attitude or heading indicators and loss of information from these instruments during IFR flight, constitutes a genuine emergency. The emergency situation may be exacerbated by the fact that the majority of vacuum-powered instruments in General Aviation airplanes do not alert pilots when their indications become unreliable. When these instruments or their vacuum sources fail, they often fail slowly and many pilots continue to follow their indications longer than they would if an abrupt failure were to occur. Once a failure is detected, the pilot must transition to partial-panel flight, ignoring the failed instruments.

Realistic instrument failure cannot be simulated in most training aircraft. Flight instructors simulate loss of attitude and heading indicators by covering instrument faces. This practice alerts students to the simulated condition and makes the transition to partial panel much easier. Realistic instrument failure can be simulated in ground-based simulators and training devices. However the element of surprise may not be as great because pilots expect failures in the simulator.

Although partial-panel training is required for certification and partial-panel skills must be demonstrated during practical tests, many certificated pilots are not prepared for in-flight instrument failure. Crashes are periodically attributed to loss-of-control following instrument failure.

Output: none

Regulatory Link: none

Requirement ID: 16

Sponsor Organization: AFS-840 POC: Tom Glista

Requirement Title: General Aviation Training

Funded Requirement:
- FY01: Yes
- FY02: No
- FY03: No
- FY04: Yes (new requirement will be submitted)

Requirement Statement: This requirement outlines the need for a thorough review of general aviation training. Not only is research required to identify potential near-term training improvements that could immediately positive effect a reduction of general aviation accidents but also the research should address training implications of future GA systems such as SATS.

Background: This research initiative will address General Aviation (GA) pilot training and required improvements that support increased pilot skills and a resultant reduced accident rate. The premise of the research is that improved airman training represents a near-term, cost-effective and meaningful method of intervention into the causative chain of events that have been identified as leading causes of GA accidents. It also suggests that new aircraft systems and capabilities providing traffic avoidance, direct routing, weather cockpit displays and other improved technologies will not be introduced in sufficient quantities in new aircraft or as retrofits to the current GA fleet in time to significantly reduce the accident rate by the year 2007.

The research will directly support the AVR mission as articulated in their FY1999 Performance Plan as well as those issues addressed by the Safer Skies program. The research will also directly contribute to the FAA Strategic Plan and FY 2000 Annual Performance Plan whereby a reduction in the aviation accident rate has been identified as a major goal.

Specifically, the training research will be designed to accomplish the following:

• Reduce GA accident rates through improved pilot training, by focusing on areas identified as known, leading, causative accident factors (Safer Skies)
• Ensure GA pilots are trained to fully utilize the capabilities of new aircraft systems as they retrofit and transition to those new systems
• Ensure the development of new GA aircraft systems is conducted in consideration of the human factors and training issues involved
• Support the development of appropriate airman evaluation and certification methods in consideration of new and emerging technologies.

• Support on-going FAA initiatives including Safer Flight, Safe Flight 21 and other programs where reduced GA accident rates are included in program goals and objectives
• Reduce the time and cost of ab initio airman certification while extending the amount of instrument training provided to all pilot applicants

This research initiative will leverage the work previously accomplished under the NASA / FAA Advanced General Aviation Transport Experiment (AGATE) program. It will address improved training technologies and techniques in today's (2000) GA operational environment as well as the probable attributes and characteristics of GA operations in the mid-term (2007) and far term (2024) where the new AGATE aircraft and the emerging Small Aircraft Transportation System (SATS) respectively will provide improved aircraft systems and NAS interface for improved flight safety. In addition, it supports the goals and objectives of the NASA Safety Program as it regards reduced GA accident rates.

The research will focus initially on near-term training improvements where immediate positive effects on reducing the GA accident rate may accrue. This focus will include current aircraft systems and technologies, as well as current and projected pilot training methods, curriculum and airman evaluation practices. The emphasis here will be on the implementation of new training processes and methods that will reduce the GA accident rate without the introduction of new aircraft systems or technologies. This initial research is critical as the implementation and use of new aircraft systems will be an incremental effort until aircraft operating those systems represent a significant percentage of GA operations. Therefore, identifying and implementing near-term training and human factors improvements will be the best avenue in achieving any meaningful, near-term reduction in GA accident rates. We will specifically investigate new training in the areas of CFIT, weather, loss of control and pilot decision-making.

Once a baseline of data is developed concerning today's GA training and operational environment, the research program will turn its attention to new aircraft systems identified for implementation in the AGATE aircraft including the Primary Flight Display (PFD), which includes the "Highway-In-The-Sky" virtual VFR system, the Multi-Functional Display (MFD), Single-Lever Power Control Systems and other increased capability. The research will identify the appropriate training and evaluation methods for these new systems to ensure full advantage is taken of their capability to reduce GA accident rates through improved pilot understanding and system familiarity.

Output: The research will additionally identify the training implications of the SATS system including the need to train pilots in the use of improved NAS information sharing and system interfaces (NAS 4.0 or better) as well as the operation of new "smart" airports and aircraft systems.
Regulatory Link: none

Requirement ID: 22

Sponsor Organization: AFS-820 POC: Anne Graham

Requirement Title: Reduction of Weather-Related and Maneuvering Flight GA Accidents

Funded Requirement:
- FY01: Yes
- FY02: Yes
- FY03: No
- FY04: Yes (new requirement will be submitted)

Requirement Statement: Weather related accidents and incidents still remains one of the major causes of general aviation accidents. This research program continues to address countermeasures and advances in training, technologies, and regulations to significantly reduce this GA issue.

Background: Weather and maneuvering flight remain the two largest single factors associated with fatal GA accidents. Typically, each of these factors accounts for about one-quarter of the approximately 400 fatal GA accidents each year. The importance of weather as a causal factor in GA accidents is reflected in its place on the administrator's Safer Skies Agenda for General Aviation. Also included in the safer Skies Agenda is Aeronautical Decision Making which is a component in both weather and maneuvering flight accidents.

Recently, a Joint Safety Analysis Team addressed the problem of weather-related accidents and produced an extensive analysis of the problems and potential solutions. The proposed solutions involve a mix of aircraft and air traffic systems, procedural changes, and human factors interventions and training. However, to successfully accomplish these solutions and to ensure that they truly have an impact on the safety of general aviation, a research program that addresses a broad range of human factors issues is required.

Although the fact that pilots sometimes venture into meteorological conditions beyond their capacity is indisputable based upon the accident statistics, the reasons for their doing so are far from clear. Anecdotal attributions of causes such as "get-home-it is" do not provide sufficient basis for the formulation of an effective intervention program. In the same way, assuming that pilots dismiss the often-heard phrase "VFR not recommended" simply because it is often-heard, is not a sufficient explanation for pilots' apparent disregard of adverse weather information.

To date, a similar depth of analysis has not been performed of maneuvering flight accidents, although they were addressed to a limited degree by the Joint Safety Analysis Team which investigated Controlled Flight Into Terrain (CFIT).

The Flight Standards Service requires that a program of research, engineering, and development be established that will:

1. Identify the human factors associated with maneuvering flight accidents and flight into instrument meteorological conditions by pilots unprepared for such conditions.
2. Develop interventions that will address the human factors identified above so as to reduce the frequency of weather-related and maneuvering flight GA accidents.
3. Develop and implement techniques to validate proposed interventions so as to ensure their acceptance, utilization, and effectiveness in the target population.

Output: none

Regulatory Link:

1. AOA (FAA) Strategic Plan (1998-2003) – Mission Goal: Safety. By 2007, reduce U.S. aviation fatal accident rates by 80% from 1996 levels (pg. 13). Focus Area: Accident Prevention. General Aviation Initiative addresses CFIT, weather, runway incursions, loss of control, and decisionmaking. (pg. 14)
2. FAA FY2000 Performance Plan -- Reduce the General Aviation Fatal Accident Rate (pg. 16).
3. AVR Performance Plan -- Goal B-1, reduce fatal aviation accident rate attributed to human error.

Requirement ID: 24

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Pilot Field-of-Vision Capabilities/Head Down Time

Funded Requirement:
- FY01: Yes
- FY02: No
- FY03: No
- FY04: No

Requirement Statement: There is a requirement to develop better ergonomic based guidance for general aviation system designers as well as FAA certification personnel on the appropriate allocation of pilot attention inside and outside the aircraft. Research data should be developed to provide the scientific-basis for this guidance.

Background: Involves the amount of time that the pilot can safely spend head down viewing instrumentation or other data sources in the cockpit before specific flight tasks are compromised (show performance degradation). Data are particularly relevant to certification issues involving the new AGATE aircraft. It might be appropriate as part of this effort to validate heads down time recommendations that have been incorporated into existing MOPS documents.

Improved safety. Provide guidance for Applicants design activities and ACO evaluations. Formulate basis for development of regulatory materiel for Part 23 FARS Involves the amount of time that the pilot can safely spend head down viewing instrumentation or other data sources in the cockpit before specific flight tasks are compromised (show performance degradation). Data are particularly relevant to certification issues involving the new AGATE aircraft.

Output: none

Regulatory Link: none

Requirement ID: 71

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Develop HF methodology for GA certification issues

Funded Requirement:
- FY01: No
- FY02: No
- FY03: No
- FY04: No

Requirement Statement: Develop methods of compliance to existing rules by establishing evaluation methodology for human factors design criteria. Analyze existing human factors guidelines e.g. GAMA publication No. 10, RTCA Moving Map MOPS, TSO for GPS equipment, etc. and establish appropriate evaluation methodologies for those recommended practices.

Background: The method of showing compliance with human factors-related regulations often involves the collection and analysis of pilot subjective data. Frequently, one or more pilots will evaluate aspects of the crew interface and determine whether, in their opinion, it met or did not meet the regulatory requirements. The approaches and procedures used by evaluation pilots to conduct these evaluations differ significantly in structure, form, and content. In some cases, pilots will simply sit in the cockpit and look around at the different areas for problems. Other pilots will use a more structured, line-oriented flight training approach that simulates the performance of flight-related tasks for the evaluation. Additionally, based on pilot individual differences, particularly in the areas of experience and training, some system aspects may be closely scrutinized while other areas may be completely overlooked. Consequently, the results and conclusions derived from these different approaches and individuals can vary considerably.

Structured, detailed subjective pilot evaluation methods need to be developed to ensure evaluations are comprehensive and effective. In particular, subjective evaluation approaches need to be developed to show compliance with Part 23 human factors-related regulations: 23.771, 23.773, 23.777, 23.779, 23.1301, 23.1311, 23.1321, 23.1322, 23.1331, 23.1367, 23.1381, and 23.1523. Research should be conducted to:· identify approaches that have been historically used to conduct such subjective evaluations,· determine the merits of these different approaches, and develop and validate an approach that may be used by the FAA and applicants to conduct means of compliance evaluations for the aforementioned regulations.

Output: none
Regulatory Link: none

Requirement ID: 72

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Establish certification requirements for the use of helmet-mounted display technology in General Aviation aircraft

Funded Requirement:
- FY01: No
- FY02: No
- FY03: No
- FY04: No

Requirement Statement: As new advanced technology is being transferred from military applications to general aviation environments there needs to be appropriate certifications standards developed to guide aviation system designers as well as FAA certification personnel. The research should examine existing standards and assure they are accurate for the GA environment as well identify any gaps and provide appropriate data to resolve these gaps.

Background: Current technology now allows head-mounted displays to be used in ways that mimic head-up displays, but that are much more flexible and do not have line-of-regard or viewing-box limitations. Systems have already been deployed for military applications, and it is clear that the emergence of lower-cost options in this field are already being capitalized upon for entertainment and personal computing. Research is already being done in applications for the civil cockpit, and it will not be long before systems are being brought forward to be considered for certification to replace HUD devices. It is desirable that standards and certification requirements be in place prior to the first submissions rather than allowing the first device on the market to set the standards, avoiding the experiences already seen with the flood of multifunction displays that arrived on the scene recently. To this end this task will involve the examination of existing data on head-mounted devices with an emphasis on the behavioral/performance consequences of design variables. To the degree that data are not available for certain questions, experimentation will be employed to fill these gaps in knowledge and add to the body of data available for defining certification requirements. Certification methods using these data also need to be developed.

Output: none

Regulatory Link: none

Requirement ID: 157

Sponsor Organization: AFS-800 POC: Michael Henry

Requirement Title: Credit for Instrument Rating in a Flight Training Device
Research Statement:

Funded Requirement:
- FY01: No
- FY02: Yes
- FY03: Yes
- FY04: Yes

Requirement Statement: Provide information required for the revision of FAR 61-141, specifying the credit hours for which various Flight Training Devices (FTDs) and Personal Computer Aviation Training Devices (PCATDs) may be used in lieu of actual flight.

Background: Modern flight training devices provide a more effective and safe training experience than aircraft. Instructor and student discuss, perform, and review specific maneuvers in a quiet environment, without the distractions of danger of other aircraft, weather, etc. FTDs provide emergency procedures often not possible in an aircraft. Further, the quality of flight training will be more uniform if the most credit is reserved for the most capable devices, and less credit granted for less capable machines.

By adjusting the flight credit allowance per the varying capabilities of FTDs, the FAA shows that it recognizes qualitative differences in the training experience. It is anticipated that a regulation change may provide incentive for further FTD development and use, and an increase in training effectiveness and efficiency.

SubTasks:

1. Evaluate all seven levels of FTDs, recategorizing them as necessary by shared characteristics (i.e., fidelity fo physical/visual/flight replication)
2. Develop a system for measuring and recording a range of pilot performance within the areas of aircraft handling, navigation, and emergency procedures.
3. Measure the performance levels of students from each of the seven FTD categories.
4. Determine the point at which performance levels in an aircraft meet pilot certification standards?

Output: An advisory circular specifying number of credit hours given in lieu of flight time.
Regulatory Link: none

Requirement ID: 187

Sponsor Organization: ACE POC: Frank Bick

Requirement Title: Priorities, organization, and sources of information accessed by pilots in various phases of flight

Funded Requirement:

- FY01: No
- FY02: Yes
- FY03: No
- FY04: No

Requirement Statement: Develop a systematic analysis of the information required by pilots in various phases of flight. To specify what information is needed, when it is needed, and how pilots conceive of the organization of the information.

Background: Validate the Schvaneveldt et al. (2000) model that determines the effect of changes in the airspace system by providing baseline information about what information pilots need and when they need it. The model can be found in in Schvaneveldt, R., Beringer, D.B., Lamonica, J., Tucker, R., and Nance, C: Priorities (2000). Organization, and sources of information accessed by pilots in various phases of flight. Civil Aviation Medical Institute (Report # DOT/FAA AM-00-26), Oklahoma City, OK.

Output: report

Regulatory Link: none

Requirement ID: 213

Sponsor Organization: AIR-130 POC: Colleen Donovan

Requirement Title: Human Performance Measures for Situation Awareness, Workload, and Trust of Flight Deck Traffic Displays in Complex Tasks and Environments

Funded Requirement:
- FY01: No
- FY02: Yes
- FY03: Yes
- FY04: Yes

Requirement Statement: The objective of this project is to find objective measurable means to determine the human performance impacts of new avionics, and specifically of new Free Flight Cockpit Display of Traffic avionics alerting systems, in terms of operators situation awareness, trust, and workload. Where objective measures are not possible, subjective means may be recommended provided they are established to be reliable and valid measures. This includes developing methods for employing these measures in both experimental and naturalistic settings. The project should be focused on developing these objective and subjective measures as minimum certification criteria, based on research and data, for approving the Free Flight technologies known as Cockpit Displays of Traffic Information (CDTI). The CDTIs may be either stand-alone units or as part of an integrated ADS-B CDTI/Traffic Collision Avoidance System (TCAS).

Background: It can be argued that the efforts to modernize the NAS and enhance both capacity and safety of the nation's air transportation system are presently technology-driven and that human factors contributions to these efforts have fallen behind the demand. The reason for this situation is apparent: The task environments in which the personnel ultimately responsible for the safe and efficient functioning of the NAS (i.e., pilots, airline dispatchers, air traffic controllers and –managers) work have increased in complexity with increase in automation applications. Consequently, scientific investigation of the impact of new technologies has become increasingly difficult due to the escalating number of variables and their interactions in the present operational environments and the shift from overt performance (i.e., manual control) to predominantly covert behavior (i.e., supervisory control) of the operators. Several constructs that attempt to describe the complex and mostly covert behaviors have been introduced. The most significant of these is situation awareness (SA), but trust and workload associated with automation are of concern as well. The measurement of these constructs is problematic, yet of critical importance.

This research will span a period of three years, with three distinct phases. Each phase may be considered individually for support, but the latter phases will depend on successful completion of the previous phases. Phase 1 and the first year efforts will focus on creating a theoretical foundation for subsequent empirical work. This phase will include exhaustive review of research literature pertaining to human performance issues associated with situation awareness, trust, and workload. The interactions of these constructs will also be examined, with an objective of identifying common underlying structures or mechanisms. This will include a review and evaluation of the Aviation Safety Reporting (ASRS) literature associated with TCAS problems, as well as other TCAS issues in order to uncover lessons learned. Special emphasis will be paid to the three "key references" listed at the end of the paper, as a potential means to develop certification standards to enable the evaluation of traffic collision alerting systems (e.g., CDTI ADS-B, TIS, and TCAS). These key reference papers propose the use of Signal Detection Theory (SDT) methodology as a means to evaluate alerting systems and separate the impact of various decision biases. SDT can be used to study the impact of changes to the decision threshold, and also the impact of changes to the a priori base rate events in the real world. The authors of these key references establish the importance not only of high hit rates and low false alarm rates, but also of the importance of high posterior probabilities of a true alarm. Additionally, they also propose a means to access the impact of these changes, despite the fact that only a handful of airplanes are equipped with ADS-B/CDTI systems, and thus it is difficult to determine the base rate information for these events, which is required to determine the posterior probabilities. Thus, one path of pursuit towards objective criteria to evaluating the CDTI alerting system is by attempting to apply the methodologies proposed and developing recommended certification criteria for the alerting systems hit rates, false alarm rates, and posterior probabilities. This methodology may prove effective in developing objective criteria for evaluating the appropriateness of an alerting system on the "trust/use/misuse/abuse" dimension. Additional methodologies and criteria would need to be developed to evaluate the situation awareness and workload dimensions.

<u>Output</u>:
At the end of each year, a comprehensive technical report will be prepared and submitted to the sponsoring agency (FAA Headquarters AAR-100 and AIR-130). These reports will detail the research Concurrently with the literature review, experimental paradigms, scenarios, and laboratory setups for activities undertaken that year as well as all results from literature reviews and experiments. In empirical evaluation of the findings from these efforts relevant to the projects objective will be initiated.

At least one laboratory experiment will be run in Phase 1. Phase 2, representing the efforts during the concurrent and complementary research efforts and developments at the FAA, NASA, and other second year of the project, will build on the results obtained in Phase 1. The primary focus will still be universities and research laboratories. On refinement, testing, and validation of human performance measures, however, the emphasis on the experimental work will shift towards increasingly complex and naturalistic tasks. In addition, it is recommended that an integrated simulation environment including both pilots and controllers as subjects without compromising the ability to accurately record data relevant to operator performance measures

Regulatory Link: none

Appendix III

Human Factors General Aviation Fiscal Year Project Planning

FY02 Funded Projects

FY03 Proposed Projects

FY04 Proposed Projects

Human Factors General Aviation

FY02 Projects (contract dollars)

Project Title	Performer	Sponsor	Req ID
Continued VFR Flight IMC: An Empirical Investigation of the Causes	University of Illinois (Doug Wiegmann)	AFS-820, Anne Graham	22
Credit for Instrument Rating in a Flight Training Device	TBD	AFS-800, Mike Henry	157
Comparison of the Effectiveness of a Personal Computer Aviation Training Device, a Flight Training Device and an Airplane in Conducting Instrument Proficiency Checks	University of Illinois (Hank Taylor)	AFS-800, Mike Henry	157
Causal Factors of Accidents and Incident Attributed to Human Error	University of Illinois (Doug Wiegmann) and CAMI (Scott Shappell)	AFS-800, Mike Henry	5
JSAT ADM panel "Human Factors Causal Analysis"	CAMI (Scott Shappell)	AFS-800, Mike Henry	5
Priorities, organization, and sources of information accessed by pilots in various phases of flight	Arizona State U (Schvaneveldt)	ACE, Frank Bick	187
Human Performance Measures for Situation Awareness, Workload, and Trust of Flight Deck Traffic Displays in Complex Tasks and Environments	University of Illinois (Esa Rantanen)	AIR, Colleen Donovan	213

Human Factors General Aviation

FY03 Proposed Projects (contract dollars)

Project Title	Performer	Sponsor	Req ID
Credit for Instrument Rating in a Flight Training Device	TBD	AFS-800, Mike Henry	157
Comparison of the Effectiveness of a Personal Computer Aviation Training Device, a Flight Training Device and an Airplane in Conducting Instrument Proficiency Checks	University of Illinois (Hank Taylor)	AFS-800, Mike Henry	157
Causal Factors of Accidents and Incident Attributed to Human Error	University of Illinois (Doug Wiegmann) and CAMI (Scott Shappell)	AFS-800, Mike Henry	5
ACE/AIR "pop up"	TBD	ACE or AIR	
Human Performance Measures for Situation Awareness, Workload, and Trust of Flight Deck Traffic Displays in Complex Tasks and Environments	University of Illinois (Esa Rantanen)	AIR, Colleen Donovan	213

Human Factors General Aviation

FY04 Proposed Projects (contract dollars and some CAMI in-house)

Project Title	Performer	Sponsor	Req ID
Credit for Instrument Rating in a Flight Training Device	TBD	AFS-800, Mike Henry	157
Comparison of the Effectiveness of a Personal Computer Aviation Training Device, a Flight Training Device and an Airplane in Conducting Instrument Proficiency Checks	University of Illinois (Hank Taylor)	AFS-800, Mike Henry	157
Causal Factors of Accidents and Incident Attributed to Human Error	University of Illinois (Doug Wiegmann) and CAMI (Scott Shappell)	AFS-800, Mike Henry	5
Weather/Visibility/GA Training	TBD	AFS-820, Anne Graham	
GA Training (SATS)	TBD	AFS-840, Tom Glista	
ACE/AIR “pop up”	TBD	ACE or AIR	
Human Performance Measures for Situation Awareness, Workload, and Trust of Flight Deck Traffic Displays in Complex Tasks and Environments	University of Illinois (Esa Rantanen)	AIR, Colleen Donovan	213